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EXAMINING THE EXPANSION POTENTIAL OF THE PETROCHEMICAL INDUSTRY IN CANADA

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Examining the Expansion Potential of the Petrochemical Industry in Canada

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Executive Summary

The Petrochemical industry in Canada is dominated by the production of ethylene from ethane and then downstream derivatives produced from ethylene. These derivatives are precursors to a wide range of useful consumer and industrial products. The sector has seen some investment in the recent past but much less than other regions globally including the US and the Middle East. This research reviews the current economic conditions of the industry and provides observations regarding the challenges for expansion.

In Canada, there are three producing regions: 1) Alberta, 2) Ontario, and 3) Québec. Seventy five percent of installed capacity is used to convert ethane to ethylene. This is only in Alberta and Ontario. Québec's petrochemical industry is quite limited, focused on feestocks obtained from crude oil refining that are further converted to produce more complex products. As such, much of the market discussion would not be a major consideration in the Québec market at this time.

The study demonstrates that the principle consideration in determining whether a region is cost competitive is the feedstock price, and second, feedstock availability in sufficient quantity. North America has this advantage over the rest of the world. The advantage is increased when there is a large price differential between natural gas and oil. The reason is that the rest of the world uses mainly oil-based feedstocks for their petrochemical production. North America and the Middle East predominantly use natural gas.

The Middle East and in particular Saudi Arabia is able to meet this cost challenge through incentives that reduce the feedstock price. Those incentives along with tidewater access and proximity to the growing Asian market makes this region globally competitive.

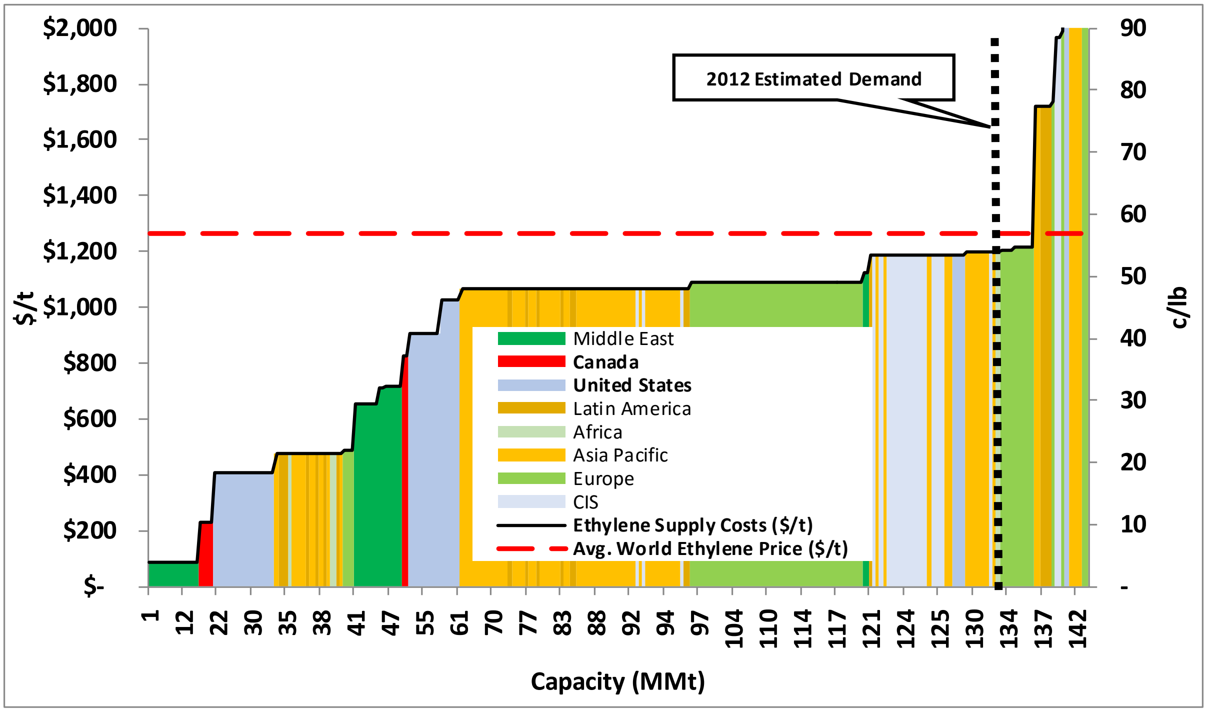
Japan and South Korea are also in competition with North America for the Chinese market in particular and their much closer proximately allows those nations to compete based on very low transportation costs.

In North America, the US Gulf Coast is developing a number of petrochemical expansion projects. This region is likely the strongest competition for Canadian manufacturers. Location incentives and co-location with derivative plants makes this area attractive for investment. In Canada, both Alberta and Ontario face challenges in comparison. There is an added expense in transporting to tidewater to access non-US export markets.

Access to feedstock is another important consideration. In Canada, CERI forecasts upwards of 350,000 barrels per day (bbl/d) of ethane availability for processing. This could support two or three world-class ethylene crackers. However, as the current infrastructure is well matched for current domestic and export demand, new infrastructure including natural gas processing and ethylene derivative plants would need to be considered at the same time as ethylene cracker units.

Overall, as Figure E.1 shows, Canada is cost competitive with the rest of the world. The Middle East has the greatest cost advantage but this is due to incentives making their feedstocks artificially low. Canada and the US are the next most competitive regions, followed by Latin America and some parts of the Asia Pacific region. This cost information is from 2012, and recent information regarding investment costs indicates the cost differentials between Canada and the US and globally between ethane and naphtha based processes are narrowing.

Figure E.1: 2012 Cost comparisons of Ethylene Supply Costs



Sources: Data from ADOE, Dewitt & Company, EIA, Federal Reserve Bank, GAE, HKEMSD, IEA, IMF, OECD, OGJ, PWC,[1] SGL, UNEP,[2] World Bank, and CERI estimates. All figures by CERI

Therefore, with suitable access to natural gas and associated liquids at a cost competitive price, there is potential to expand the petrochemical sector in this country.

Challenges that need to be addressed include:

- developing off-shore markets for natural gas to increase the supply of natural gas liquids, especially ethane,

[1] PWC, Shale gas, Reshaping the US chemicals industry: http://www.pwc.com/en_US/us/industrial-products/publications/assets/pwc-shale-gas-chemicals-industry-potential.pdf
[2] United Nations Environmental Programme, Global Chemicals Outlook (2013): http://www.unep.org/hazardoussubstances/Portals/9/Mainstreaming/GCO/The%20Global%20Chemical%20Outlook_Full%20report_15Feb2013.pdf

- added infrastructure for separating sufficient ethane from incremental natural gas production, and
- adequate logistics support for getting product to markets.

Chapter 1: An Introduction to the Canadian Petrochemical Industry

The advent of shale gas development in North America has led to a wave of natural gas liquids (NGLs) extraction that has benefitted petrochemical producers across North America. Within the Canadian context, this project examines the conditions that would potentially lead to expansion of the petrochemical industry. The focus of this project is to build upon previous work completed by CERI in the context of the latest NGLs study update.

The NGLs study update introduced the importance of the petrochemical industry in the context of the NGLs value chain. It identified the feedstocks that are currently in surplus positions within the Canadian context and for which there is a potential to expand domestic demand via the expansion of the petrochemical industry. This is generally the case for natural gas, ethane, propane, and butanes.

Given the global nature of the petrochemical industry and the fact that many of the large petrochemical manufacturers have global operations, Canada is competing against other manufacturing areas around the world for investment capital. This study will highlight important characteristics of other petrochemical clusters around the world in order to better understand how Canadian petrochemical clusters can expand based on feedstock availability.

Overview of the Canadian Petrochemical Industry

This section is an overview of the main product chains manufactured by the petrochemical industry in Canada as well as the existing regional clusters and their differences. The main purpose of this section is to provide an overview of what petrochemicals are, what the petrochemical industry does, and the main facilities and clusters across the country.

When describing petrochemicals (petroleum-based chemicals), there are two major basic building blocks (or groups):

1. *olefins* such as ethylene ($C_{2=}$), propylene ($C_{3=}$), and C_4 olefins (such as butadiene, butene, and isobutylene), and
2. *aromatics* such as benzene, toluene, and xylenes (BTX).

As illustrated in Figure 1.1, these basic chemicals then get used to produce chemical derivatives or intermediates (aka polymers/polyolefins) like polyethylene (PE), polypropylene (PP), etc., which are subsequently used to produce end-use products that are used in our daily lives including various grades of plastics, resins, fibres, and solvents.

Figure 1.1: Petrochemical Process

Raw resources extraction

- Crude oil: conventional and unconventional (oil sands, light-tight oil (LTO), etc.)
- Raw natural gas: natural gas (methane: CH_4), natural gas liquids (NGLs: C_2, C_3, C_4, C_{5+}) , and other components (CO_2, H_2O, H_2S, He, and N_2)
- Coal and biomass:synthesis gas (syngas: carbon monoxide (CO)/hydrogen (H_2)) to methanol (MeOH)

Processing (separation) and transformation

- Crude oil refining: separation of crude oil fractions
- Refined petroleum products (RPPs) such as transporation and heating fuels (propane/butanes (LPG), gasoline, diesel, kerosene, etc.), waxes, lubricants, petrochemical feedstocks (LPG, naphtha, and gas oil), and petrochemicals such as olefins (propylene/ethylene), and aromatics (bezene, toluene, and xylenes (BTX))
- Natural gas processing: removal of impurititès (CO_2, H_2O, H_2S, He, and N_2), and extraction/ separation of NGLs
    - Sales gas (mainly (CH_4); NGLs (C_2 - C_{5+}); Sulfur and other
- Coal/biomass gasification and natural gas steam methane reforming (SMR): synthesis gas (syngas: carbon monoxide (CO)/hydrogen (H_2)) to methanol (MeOH)

Feedstocks for base chemicals (petrochemicals)

- Crude oil refinery: LPG (C_3/C_4), naphtha, and gas oil
- NGLs fractionation: Ethane, propane, butanes, and pentanes plus
- Coal and biomass gasification: syngas --> methanol
- Natural gas: SMR --> methanol

Conversion processes: from feedstock to petrochemicals

- Steam cracking (SC): main process. Its primary purpose is production of olefins. Yields of products/co-products depends on feedstock (lighter feedstock (C_2/C_3): more olefins (C_2-C_{4s})/heavier feedstock (C_4, C_{5+}, C_6 - C_8): more aromatics (C_6 - C_8)). Main product streams: Olefins (gases) ;Aromatics/pyrolisis gasoline (pygas) (liquids); Fuel gas; Other lliquids
- Propane de-hydrogenation (PDH): production of on-purpose propylene by removing H_2 from propane
- Methanol to olefins (MTO): production of olefins from methanol

Olefins and aromatics (petrochemicals)

- Olefins (from steam cracking, crude oil refining, PDH, and MTO): Ethylene, Propylene, and mixed C4s
- Aromatics (from crude oil refining and steam cracking): BTX
- Other components: fuel gas (CH_4/H_2) and other liquids (non-aromatics, heavy aromatics, and fuel oil)

Polymerization/conversion: petrochemicals to derivatives/intermediates

- Polyethylene teraphthalate (PET: Plastic #1)
- High-density and low-density polyethylene (HDPE: #2/LDPE: #4)
- Polyvinyl chloride (PVC: #3)
- Polypropylene (PP: #5)
- Polystyrene (PS: #6)
- (Note: PE, PP, and PVC, are made from olefins only. PET and PS are made from a combination of olefins and aromatics)

Manufactured/end-use products

- Synthetic fibers and plastic bottles
- Plastics bags and films
- Cables and diapers
- Windows and pipes
- Carpets, car parts, and bank notes
- Food packaging, CD cases, and disposable utensils
- Gasoline
- Solvents

Olefins vs. Aromatics

Olefins are produced primarily via steam cracking (ethylene cracking) using feedstock such as natural gas liquids (ethane, propane, butanes, and pentanes plus). They are also produced with refined petroleum products such as naphtha and gas oil. Olefins are produced during the crude oil refining process (primarily propylene but also some ethylene), and other processes which might not be significant in terms of total production volumes today. However, they are increasingly gaining prominence, including propane dehydrogenation (PDH)[3] and methanol to olefins (MTO).[4]

The steam cracking process' main purpose is the production of ethylene, yet various other co-products result from the process. These include other olefins such as propylene and mixed C4s olefins, pyrolysis gasoline (pygas), BTX, fuel gas, fuel oil, as well as other non-aromatic and heavier aromatic components. The proportion of ethylene produced by the steam cracking process is directly related to the feedstock being used. Lighter feedstock such as ethane produce around 80 percent ethylene on a tonne/tonne basis,[5] and about 20 percent co-products (other olefins, pygas, etc.), while a feedstock such as pentanes plus or naphtha will yield about 25 percent ethylene and 75 percent co-products. Generally, the lighter the feedstock (e.g., ethane and propane) the higher the ethylene yield from steam cracking and the lower the co-product yield. Both refineries and steam crackers produce olefins (such as ethylene and propylene) as well as aromatics (such as BTX) and other co-products. Thus, the primary types of petrochemical facilities in Canada include olefin (or steam) crackers and refineries (aromatics plants). Aromatics are produced primarily via refining.

Basic petrochemicals such as olefins and aromatics are then used to produce derivatives or intermediate products such as different grades of polyethylene, polypropylene,[6] polystyrene (PS), etc. Because olefins are generally produced in a gaseous state, downstream integration of derivatives is usually the case with steam crackers. Therefore, a steam cracker will generally produce enough ethylene according to downstream demand.

Derivatives are then used to produce end-use manufactured products such as plastic bags and films, fibres, solvents, etc. Ethylene and co-products are used as feedstock in derivative plants to make end-use products. Some co-products can be used as finished products such as propylene and BTX for gasoline blending. However, ethylene, similar to ethane, is neither easy to transport (other than via high vapor pressure pipelines) nor store (compressed gas into liquid form), and generally tends to be turned into other products on site. As such, ethylene crackers are usually built in conjunction with ethylene derivative plants.

[3] In PDH, propane is used to produce on-purpose propylene
[4] The MTO process involves the production of olefins from methanol, which is in turn produced from syngas that can be produced via gasification of coal and biomass but also steam methane reforming (SMR) (of natural gas)
[5] That is, one tonne of ethane yields 0.8 tonnes of ethylene
[6] Polyethylene and PP are generally produced as thermo-plastic pellets which can then be used to manufacture different types of products

The primary output from refineries is refined petroleum products such as gasoline and diesel. However, refineries also produce liquefied petroleum gases (LPGs), naphtha and gas oils, which can be used as a feedstock for steam crackers. They also produce propylene and BTXs, which can be used in derivative plants or as gasoline blend stock.

BTXs can be used for the manufacturing of styrene monomer, solvents, paints, pesticides, and other finished products. Refineries' BTX yields will depend on the refinery configuration and their crude feedstock as well as their downstream integration to chemical complexes.

Regional Clusters

In Canada, there are three major petrochemical clusters. These are located in Alberta (Joffre and Ft. Saskatchewan), Ontario (Sarnia-St. Clair), and Québec (East Montreal). Further details on these regional clusters are described below.

Alberta

In Alberta, the petrochemical industry is primarily based on ethylene cracking facilities (olefins) (about 92 percent of petrochemical production capacity), while there is also an aromatics-based facility (at the Shell Scotford site). Steam crackers in Alberta are configured to use ethane as a feedstock with a small degree of flexibility to crack some volumes of propane when ethane supply is constrained or when propane offers a cost advantage. This highlights the fact that the petrochemical industry in Alberta is reliant on supply of NGLs, primarily ethane, which is tied to production and processing of natural gas.

Table 1.1 displays Alberta olefin facilities together with the respective ethylene derivative plants and aromatic plants (as parts of refining complexes) from where BTX is produced for end-use products.

Table 1.1: Alberta Petrochemical Plant Information (2012)

ALBERTA							
Company	Facility	Location	Main Product	Plant Capacity (kt/yr)	Feedstock	Required Feedstock (kb/d)
Ethylene Crackers (Olefins)						
NOVA Chemicals	Ethylene 1 (E1)	Joffre Complex, AB	Ethylene	726	C2/ Some C3	45
NOVA Chemicals	Ethylene 2 (E2)	Joffre Complex, AB	Ethylene	816	C2/ Some C3	51
NOVA Chemicals (50%)/ Dow Chemicals (50%)	Ethylene 3 (E3)	Joffre Complex, AB	Ethylene	1,270	C2	79
Dow Chemicals	Dow Fort Saskatchewan (LHC1)	Fort Saskatchewan, AB	Ethylene	1,285	C2	80
Total Ethylene Crackers				***4,097***		***255***
Aromatics Plants						
Shell Canada	Shell Scotford Refinery	Scotford, AB	Benzene	370	Crude Oil	n/a
Total Aromatics				***370***		
Ethylene Derivatives						
						Required Feedstock (kt/yr)
Polyethylene and Similar Products						
NOVA Chemicals	Polyethylene 1 (PE1)	Joffre Complex, AB	LLDPE	671	Ethylene	678
NOVA Chemicals	Polyethylene 2 (PE2)	Joffre Complex, AB	LLDPE & HDPE	431	Ethylene	435
INEOS Oligomers	Joffre Linear Alpha Olefins (LAO) Plant	Joffre Complex, AB	LAO	250	Ethylene	253
Dow Chemicals	Prentiss PE	Red Deer, AB	LLDPE	500	Ethylene	505
Dow Chemicals	Fort Saskatchewan PE	Fort Saskatchewan, AB	LLDPE	850	Ethylene	859
Celanese (AT Plastics)	Edmonton EVA Manufacturing Plant	Edmonton, AB	LDPE, EVA	143	Ethylene	61
Total				***2,845***		***2,790***
Ethylene Glycol						
ME Global (50% owned by Dow Chemicals)	Prentiss I Ethylene Oxide/ Ethylene Glycol (EO/EG) Plant	Red Deer, AB	MEG	310	Ethylene	179
ME Global (50% owned by Dow Chemicals)	Prentiss II EO/EG Plant	Red Deer, AB	MEG	285	Ethylene	165
ME Global (50% owned by Dow Chemicals)	Fort Saskatchewan (FS) 1EO/ EG Plant	Fort Saskatchewan, AB	EO/EG	350	Ethylene	202
Shell Chemicals Canada Ltd.	Shell Chemicals Scotford Manufacturing Monoethylene Glycol (MEG) Plant	Scotford, AB	MEG	450	Ethylene	260
Total				***1,395***		***806***
Styrene Monomer						
Shell Chemicals Canada Ltd.	Shell Chemicals Scotford Manufacturing Styrene Monomer (SM) Plant	Scotford, AB	SM	450	Ethylene	121
					Benzene	365
Total				***450***		***486***
Other Facilities						
Keyera Corp.	Alberta EnviroFuels (AEF)	Edmonton, AB	Iso-octane	521	Field Butanes (f-C4)	n/a
Williams Canada	Redwater Fractionator/ Propylene Plant	Redwater, AB	PGP	68	SGLs Mix	n/a
Total				***589***		

Sources: Data from AED,[7] AIEM,[8] BMI,[9] CERI research,[10] MEI,[11] Industry data, OGJ data,[12] and Sarnia-Lambton Economic Partnership.[13] Tables by CERI

[7] Alberta Chemical Operations, Alberta Economic Development (AED), May, 2000: http://www.nelson.com/albertascience/0176289305/student/weblinks/documents/ChemicalOperationsDirectory.pdf
[8] Association Industrielle de l'est de Montreal (AIEM), Membres et types d'industries: http://www.aiem.qc.ca/index.php?option=content&task=view&id=11&Itemid=106
[9] Business Monitor International (BMI), Canada Petrochemicals Report, 2013: http://www.marketresearch.com/Business-Monitor-International-v304/Canada-Petrochemicals-7287960/
[10] Including: Canadian Energy Research Institute (CERI): The Sarnia Complex, Synergies and Strategies, Study No. 68. December, 1995
[11] Montreal Economic Institute (MEI), the Economic Benefits of Pipeline Projects to Eastern Canada: http://www.iedm.org/files/note0813_en.pdf
[12] Oil & Gas Journal (OGJ), International Survey of Ethylene From Steam Crackers – 2013: http://www.ogj.com/articles/print/volume-111/issue-7/special-report-ethylene-report/international-survey-of-ethylene-from.html
[13] Sarnia-Lambton Petrochemical and Refining Complex, October 2013: http://www.sarnialambton.on.ca/medialibrary/5/S_L_PETROCHEM_BROCH.pdf

Ontario

Table 1.2 displays Ontario olefin facilities together with the respective ethylene derivative plants and aromatic plants from where BTX is produced for end-use products.

Table 1.2: Ontario Petrochemical Plant Information (2012)

ONTARIO						
Company	Facility	Location	Main Product	Plant Capacity (kt/yr)	Feedstock	Required Feedstock (kb/d)
Ethylene Crackers (Olefins)						
NOVA Chemicals	Corunna, Ethylene	Corunna, ON	Ethylene	839	C2,C3,C4,C5+	67
Imperial Oil Products & Chemicals	Imperial Sarnia	Sarnia, ON	Ethylene	300	C2,C3,C4,C5+	23
Total Ethylene Crackers				*1,139*		*90*
Aromatics Plants						
Benzene						
Imperial Oil	Imperial Sarnia	Corunna, ON	Benzene	110	Crude Oil/ NGLs	n/a
Nova Chemicals	Corunna, Ethylene	Sarnia, ON	Benzene	120	Crude Oil/ NGLs	n/a
Shell	Shell Sarnia	Sarnia, ON	Benzene	60	Crude Oil	n/a
Sunoco Chemicals (Suncor)	Suncor Sarnia	Sarnia, ON	Benzene	50	Crude Oil	n/a
Total Benzene				*340*		
Toluene						
Imperial Oil	Imperial Sarnia	Sarnia, ON	Toluene	85	Crude Oil/ NGLs	n/a
Shell	Shell Sarnia	Sarnia, ON	Toluene	130	Crude Oil	n/a
Sunoco Chemicals (Suncor)	Suncor Sarnia	Sarnia, ON	Toluene	207	Crude Oil	n/a
Total Toluene				*422*		
						Required Feedstock (kt/yr)
Ethylene Derivatives						
Polyethylene and Similar Products						
NOVA Chemicals	St. Clair River, Corunna, ON PE	Corunna, ON	HDPE	204	Ethylene	194
NOVA Chemicals	Mooretown, ON PE	Mooretown, ON	HDPE	211	Ethylene	200
NOVA Chemicals	Mooretown, ON PE	Mooretown, ON	LDPE	170	Ethylene	161
Imperial Oil Products & Chemicals	Sarnia PE	Sarnia, ON	HDPE	470	Ethylene	446
Total				*1,055*		*1,002*
Styrene Monomer						
Styrolution	Styrolution Sarnia Production Site	Sarnia, ON	SM	431	Ethylene	116
					Benzene	339
Total				*431*		*455*
Other Facilities						
Lanxess Inc.	Sarnia Site	Sarnia, ON	Butyl Rubber	150	Mixed C4's, Butylene, Butadiene, Styrene, Other	n/a
Total				*150*		

Sources: Data from AED,[14] AIEM,[15] BMI,[16] CERI research,[17] MEI,[18] Industry data, OGJ data,[19] and Sarnia-Lambton Economic Partnership.[20]

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[14] Alberta Chemical Operations, Alberta Economic Development (AED), May, 2000: http://www.nelson.com/albertascience/0176289305/student/weblinks/documents/ChemicalOperationsDirectory.pdf

[15] Association Industrielle de l'est de Montreal (AIEM), Membres et types d'industries: http://www.aiem.qc.ca/index.php?option=content&task=view&id=11&Itemid=106

[16] Business Monitor International (BMI), Canada Petrochemicals Report, 2013: http://www.marketresearch.com/Business-Monitor-International-v304/Canada-Petrochemicals-7287960/

[17] Including: Canadian Energy Research Institute (CERI): The Sarnia Complex, Synergies and Strategies, Study No. 68. Dec, 1995

[18] MEI, the Economic Benefits of Pipeline Projects to Eastern Canada: http://www.iedm.org/files/note0813_en.pdf

[19] Oil & Gas Journal (OGJ), International Survey of Ethylene From Steam Crackers – 2013: http://www.ogj.com/articles/print/volume-111/issue-7/special-report-ethylene-report/international-survey-of-ethylene-from.html

[20] Sarnia-Lambton Petrochemical and Refining Complex, October 2013: http://www.sarnialambton.on.ca/medialibrary/5/S_L_PETROCHEM_BROCH.pdf

In Ontario, about 60 percent of the province's petrochemical capacity is based on olefins and 40 percent on aromatics (toluene and benzene). Historically, feedstock for olefins facilities have been sourced from western Canada (NGLs and crude oil/condensate),[21] and local refineries (LPG). Aromatics-based facilities sourced their feedstock from local refineries (which in turn source their crude oil from western Canada and overseas) and local olefin crackers. More recently, NGLs (primarily ethane and propane) are being imported from the United States to feed steam crackers. Increased connectivity with western Canada has diminished crude oil refining and aromatics-based facilities' dependence on crude oil imports.

Québec

In Québec, the industry is based on aromatics (benzene and toluene) primarily produced at the Suncor refinery. In 2008, the Petromont ethylene cracker, the only olefins based facility was closed down. Table 1.3 displays Québec facilities together with the respective derivative plants.

[21] Nova Chemicals had a refining facility to separate light crude and condensate into LPG, naphtha, and aromatic fractions

Table 1.3: Québec Petrochemical Plant Information (2012)

QUEBEC						
Company	Facility	Location	Main Product	Plant Capacity (kt/yr)	Feedstock	Required Feedstock (kt/yr)
Aromatics Plants						
Benzene						
Suncor	Suncor Refinery/ Petrochemicals	Montreal, QC	Benzene	350	Crude Oil	n/a
Total				***350***		
Toluene						
Suncor	Suncor Refinery/ Petrochemicals	Montreal, QC	Toluene	240	Crude Oil	n/a
Total				***240***		
Other Facilities						
Aromatics Derivatives						
p-Xylene						
ParaChem Chemicals (Suncor)	Montreal Site	Montreal, QC	p-Xylene	350	Benzene & Toluene	n/a
Total				***350***		
Xylene/PTA Derivatives						
Interquisa Canada (CEPSA Chimie)	Montreal Site	Montreal, QC	PTA	500	p-Xylene	350
Selenis	Montreal Site	Montreal, QC	PET	150	PTA	345

Sources: Data from AED,[22] AIEM,[23] BMI,[24] CERI research,[25] MEI,[26] Industry data, OGJ data,[27] and Sarnia-Lambton Economic Partnership.[28] CERI

[22] Alberta Chemical Operations, Alberta Economic Development (AED), May, 2000: http://www.nelson.com/albertascience/0176289305/student/weblinks/documents/ChemicalOperationsDirectory.pdf

[23] Association Industrielle de l'est de Montreal (AIEM), Membres et types d'industries: http://www.aiem.qc.ca/index.php?option=content&task=view&id=11&Itemid=106

[24] Business Monitor International (BMI), Canada Petrochemicals Report, 2013: http://www.marketresearch.com/Business-Monitor-International-v304/Canada-Petrochemicals-7287960/

[25] Including: Canadian Energy Research Institute (CERI): The Sarnia Complex, Synergies and Strategies, Study No. 68. Dec, 1995

[26] MEI, the Economic Benefits of Pipeline Projects to Eastern Canada: http://www.iedm.org/files/note0813_en.pdf

[27] Oil & Gas Journal (OGJ), International Survey of Ethylene From Steam Crackers – 2013: http://www.ogj.com/articles/print/volume-111/issue-7/special-report-ethylene-report/international-survey-of-ethylene-from.html

[28] Sarnia-Lambton Petrochemical and Refining Complex, October 2013: http://www.sarnialambton.on.ca/medialibrary/5/S_L_PETROCHEM_BROCH.pdf

Figure 1.2 shows the locations of the regions and the split between olefin and aromatic production capacity. The included chart shows the percentage of olefin production for Canada at approximately 75 percent.

Figure 1.2: Petrochemical Manufacturing Regions and Their Olefin and Aromatic Production (kt/yr)

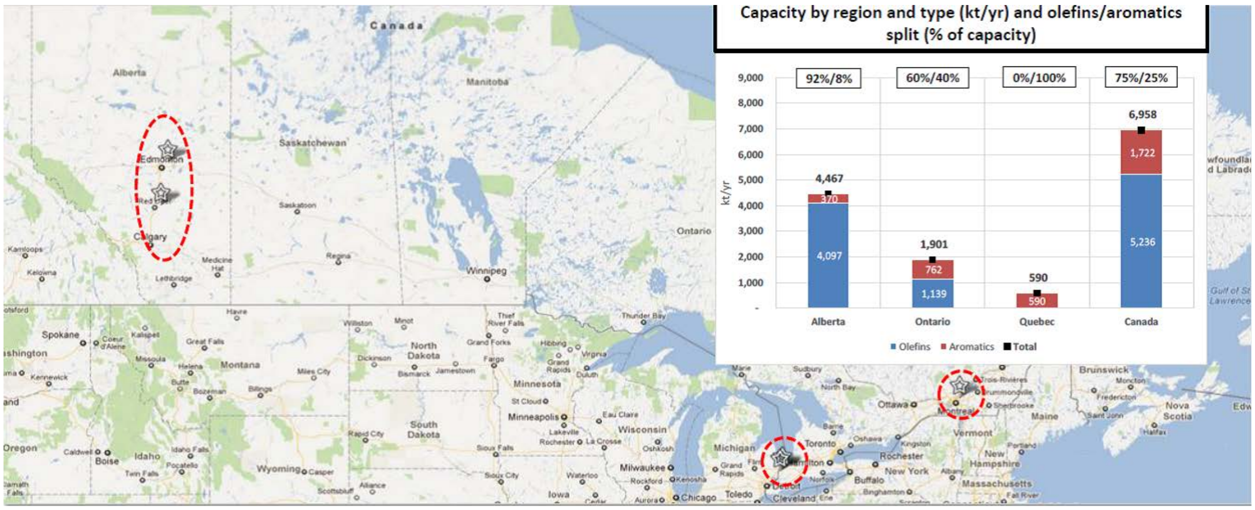


Image from GoogleMaps; Modified by CERI

Supply and Demand Balances

Table 1.4 provides a summary of the three major Canadian petrochemical clusters and the interaction between the steam crackers, aromatic plants, and their derivative plants.

Seventy eight percent of ethylene cracking capacity is in Alberta, with the largest concentration around the Joffre complex. All ethylene crackers combined have the potential to use a total of about 342 kb/d of NGLs and heavier feedstock[29] (255 kb/d in Alberta, and 87 kb/d in Ontario). In turn, these facilities have the capacity to produce 5,236 thousand tonnes (kt)[30] of ethylene per year. Estimated co-product capacity for these facilities is over 2,003 kt per year.[31]

[29] Based on OGJ data for the start of 2013, the feedstock requirement is about 274 kb/d of ethane, 28 kb/d of propane, 20 kb/d of butane, and 19 kb/d of Naphtha, for a total of 342 kb/d of ethylene cracking feedstock.
[30] There are 2,205 lbs in a metric ton or *tonne* (t)
[31] Net of BTX as listed in Table 1.6/Co-product production will vary significantly based on feedstock used.

Table 1.4: Major Petrochemical Clusters in Canada, Summary

ALBERTA

From: Petrochemical Plants			To: Derivative Plants	
Type	**Capacity (kt/yr)**		**Feedstock Req. (kt/yr)**	**Type**
Olefins Plants				
Ethylene Crackers	4,097	68%	2,790	Polyethylene/ Similar Plants
		20%	806	MEG Plants
		3%	121	SM Plant
	Total	**91%**	**3,717**	**Total Derivative Plants**
	Balance	9%	380	Excess Capacity
Aromatics Plants				
Benzene	370	99%	365	SM Plant
	Total	**99%**	**365**	**Total Derivative Plants**
	Balance	1%	6	Gasoline Blend, Industrial Chemicals, and Solvents

ONTARIO

From: Petrochemical Plants			To: Derivative Plants	
Type	**Capacity (kt/yr)**		**Feedstock Req. (kt/yr)**	**Type**
Olefins Plants				
Ethylene Crackers	1,139	88%	1,002	Polyethylene/ Similar Plants
		10%	116	SM Plant
	Total	**98%**	**1,118**	**Total Derivative Plants**
	Balance	2%	21	Excess Capacity
Aromatics Plants				
Benzene	340	100%	339	SM Plant
	Total	**100%**	**339**	**Total Derivative Plants**
	Balance	0%	1	Gasoline Blend, Industrial Chemicals, and Solvents
Toluene	422	100%	422	Gasoline Blend, Industrial Chemicals, and Solvents
	Total	**100%**	**422**	**Total Derivative Plants**
	Balance	0%	-	

QUEBEC

From: Petrochemical Plants			To: Derivative Plants	
Type	**Capacity (kt/yr)**		**Feedstock Req. (kt/yr)**	**Type**
Aromatics Plants				
Benzene	350	100%	350	Benzene Derivatives (Including p-X plant) & Refinery Feedstocks
	Total	**100%**	**350**	**Total Derivative Plants**
	Balance	0%	-	
Toluene	240	100%	240	Toluene Derivatives (Including p-X plant) & Refinery Feedstocks
	Total	**100%**	**240**	**Total Derivative Plants**
	Balance	0%	-	

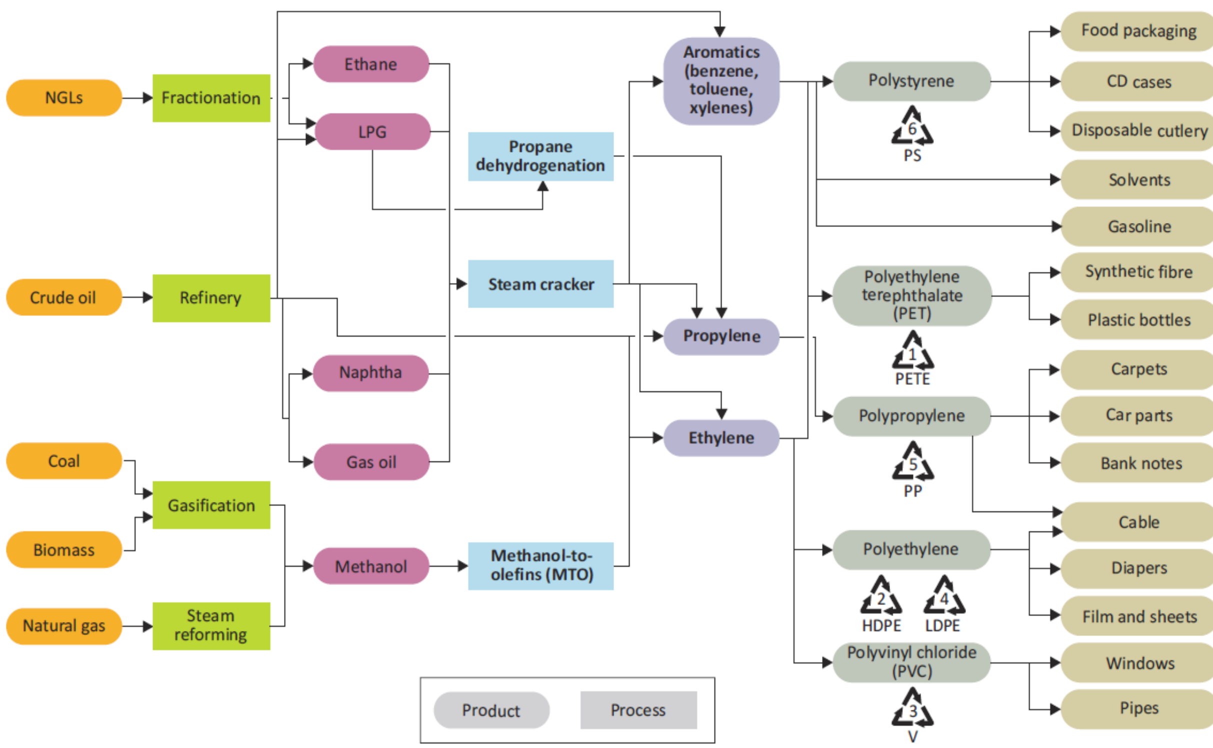
CANADA

From: Petrochemical Plants			To: Derivative Plants	
Type	**Capacity (kt/yr)**		**Feedstock Req. (kt/yr)**	**Type**
Olefins Plants				
Ethylene Crackers	5,236	72%	3,791	Polyethylene/ Similar Plants
		15%	806	MEG Plants
		5%	237	SM Plants
	Total	**92%**	**4,834**	**Total Derivative Plants**
	Balance	8%	402	Excess Capacity
Aromatics Plants				
Benzene & Toluene Plants	1,722	41%	704	SM Plants
	Total	**41%**	**704**	**Total Derivative Plants**
	Balance	59%	1,018	Other Benzene & Toluene Derivatives (Including p-X plant) & Refinery Feedstocks

Feedstock Requirements and the Importance of NGLs

Figure 1.3 provides a simplified flow diagram of petrochemical feedstock sources and end products.[32] The petrochemical industry provides an important link between hydrocarbon producers and finished goods by transforming natural resources to end-use manufactured consumer products for everyday needs. By doing so, the petrochemical industry adds incremental economic value to those hydrocarbon resources.

Figure 1.3: Petrochemical Feedstock and End-use Flowchart



Source: International Energy Agency (IEA)[33]

In the Canadian context, the main sources of petrochemical feedstock include NGLs from processing plants and off-gas plants as a feedstock for olefin or ethylene crackers in Alberta and Ontario. Crude bitumen, crude oil, and condensates processed at refineries are another feedstock, which yield LPG's, as well as refinery naphtha and gas oils for steam crackers.

One of the main links between olefin and aromatics facilities is the styrene monomer (SM) plants, which manufacture styrene by dehydrogenation of ethylbenzene. This is initially produced by synthesizing ethylene and benzene.

[32] The following sections are taken from the CERI STUDY: Natural Gas Liquids (NGLSs) in North America: An Update Part II-Midstream and Downstream Infrastructure pp. 24 – 33: http://ceri.ca/images/stories/2014-05-06_CERI_Study_139_Part_II.pdf
[33] International Energy Outlook, World Energy Outlook 2013. Available at: http://www.worldenergyoutlook.org/publications/weo-2013/

Table 1.4 provides information on facilities that produce various grades of polyethylene and similar products (including ethylene vinyl acetate (EVA) and linear-alpha olefins (LAOs) in Canada. Over 70 percent of this capacity is located in Alberta. These PE, EVA, and LAO plants have the capacity to absorb close to 3,791 kt/yr of ethylene and produce 3,817 kt/yr of plastics.

Other derivative plants, including mono ethylene glycol (MEG) and styrene monomer plants have the capacity to use an estimated 1,043 kt/yr of ethylene feedstock and produce over 2,276 kt/yr of products.

Thus, combined, polyethylene, EVA, LAO, MEG, and SM plants have the capacity to absorb a total of close to 4,834 kt/yr of ethylene feedstock and produce about 6,093 kt/yr of output. This implies that currently, in Canada as a whole, there is an ethylene production capacity surplus of about 402 kt/yr. This surplus, in turn, translates into a feedstock requirement of about 25 kb/d of NGLs/naphtha and makes the demand for olefins petrochemical feedstock in Canada about 317 kb/d of NGLs/naphtha.[34]

Table 1.4 illustrates this point, and shows that the current ethylene production capacity surplus situation is particular to AB. In order for ethylene cracking nameplate capacity to be fully utilized in Alberta, not only should there be enough ethane feedstock supplied in the WCSB, but derivative plant investments are required. These investments will in turn lead to an increase in ethane use.

Ongoing investments are taking place to increase feedstock availability in Alberta partly stimulated by the Incremental Ethane Extraction Policy (IEEP). NOVA Chemicals is currently building a new polyethylene reactor at its Joffre complex. It has publicly disclosed the possibility of ethylene capacity de-bottlenecks to monetize increasingly available NGLs in Canada.

In the Sarnia area,[35] additional NGL feedstock capacity is being developed through the Mariner West and UTOPIA pipelines. This could potentially exceed feedstock requirements for ethylene crackers and derivative plants in the area, creating an opportunity for ethylene cracking expansion.

In regards to aromatics plants, production capacity is mainly located in Ontario and Québec. While benzene production appears to be fully utilized in Alberta and Ontario, by the SM plants, benzene production in Québec must be allocated to other uses such as gasoline blending. It could also feed the para-xylene plant in Montreal.[36]

Toluene production around Sarnia is assumed to be used internally by refineries. Some of the toluene around Montreal is used at the para-xylene plant and the remainder internally.

[34] 342 kb/d – 25 kb/d = 317 kb/d

[35] Nova's Corunna cracker has been re-tooled to maximize NGL use, thus limiting and eliminating C5+/heavy feeds

[36] Dow Chemicals has a manufacturing site in Varennes, QC, which produces STYROFOAM. While not much information is available on this plant there is a possibility that some of the benzene around the Montreal area is used by this plant

Other petrochemical facilities in Canada include the Alberta EnviroFuels (AEF) facility, which produces iso-octane from field butanes (f-butanes) for gasoline blending.

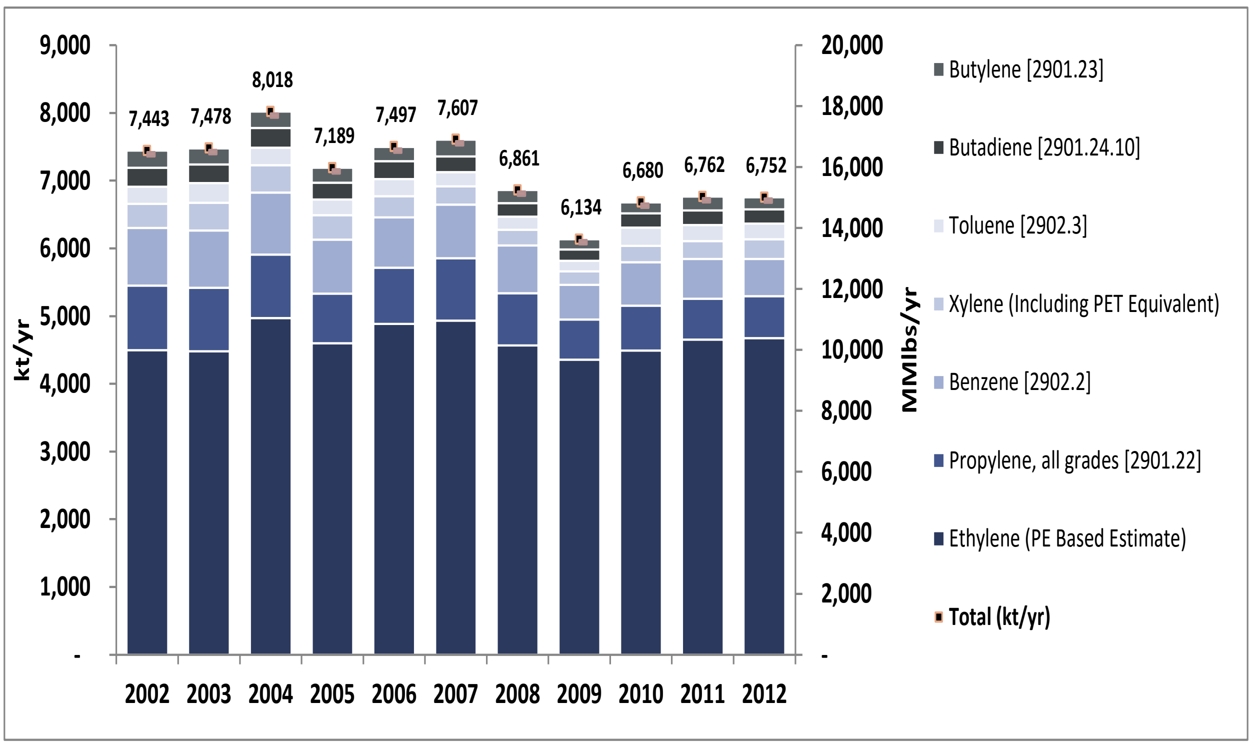
The Williams Redwater fractionator in Alberta produces olefins from the processed off-gas SGLs mix including ethylene, polymer-grade propylene (PGP), and butylene used as alky-feed for gasoline.

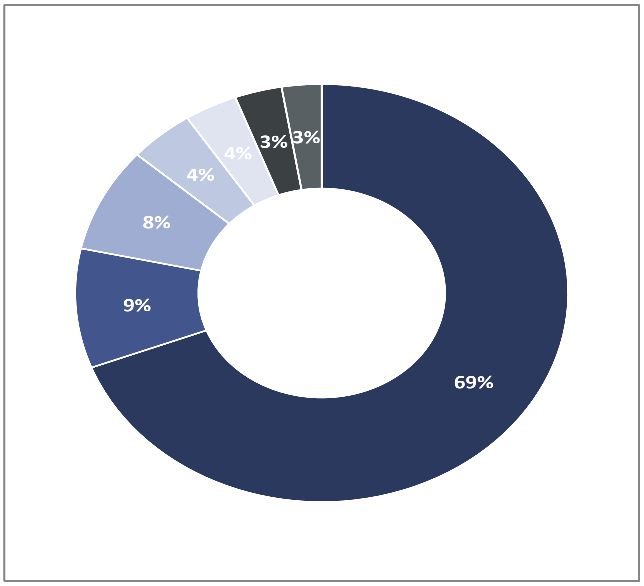
In Sarnia, Lanxess uses butanes, butylene, butadiene, styrene, and other chemicals to produce various grades of rubbers and other products. In addition, in Montreal, para-xylene (p-xylene) made using benzene and toluene is used for the production of purified terephthalic acid (PTA). This in turn is used to manufacture polyethylene terephthalate (PET) for plastic goods such as water bottles.

Production

Figure 1.4 provides a breakdown of petrochemical production in Canada from 2002 to 2012.

Figure 1.4: Canadian Petrochemical Production (kt/yr) (2002 - 2012) and 2012 % Share of Total





Source: Data from Industry Canada,[37] Statistics Canada,[38] and CERI estimates. Figures by CERI

The first apparent trend is that overall petrochemical production levels declined between 2002 and 2009. They have since recovered to stable levels around 6,800 kt/yr over the last few years (2011-2012) in line with overall economic activity. By 2012, ethylene, propylene, benzene, and xylenes (combined) accounted for 90 percent of petrochemical production in Canada.

Since most petrochemicals are used to manufacture consumer goods, production is very much driven by overall economic activity and growth. During the 2008-2009 economic downturn, overall production levels of petrochemicals in Canada was commensurate with lower demand and sluggish economic activity. However, a large portion of polyethylene and other derivatives are exported primarily to the US and other markets, thus economic activity in those markets affects demand and production levels for petrochemicals in Canada.

A large portion of world petrochemical production capacity is based on crude oil derived feedstock such as naphtha.[39] This makes them the marginal cost suppliers and the price setters. In addition, crude oil prices (as well as processing costs) are directly tied to the price for petrochemical intermediates, derivatives, and consumer goods. As such, demand and production levels adjust according to commodity price levels and cycles as well.

[37] Industry Canada, Industries and Business, Canadian Chemical Industry, Industry Profiles, Petrochemicals Industrial Profile: http://www.ic.gc.ca/eic/site/chemicals-chimiques.nsf/eng/bt01135.html
[38] Table 303-0053, Production of industrial chemicals and synthetic resins.
Table 303-0014, Production of industrial chemicals and synthetic resins.
Available at: http://www5.statcan.gc.ca/cansim/a33?RT=TABLE&themeID=512&spMode=tables&lang=eng
[39] This is discussed in more detail in Part IV of the NGLs Update

In 2008, Petromont closed its ethylene cracker and polyethylene unit[40] in Montreal (for which the primary feedstock was naphtha and gas oil), thus taking off-line about 300 kt/yr from total ethylene capacity in Canada as well as associated co-products.

Compared to 2002 levels, production of all petrochemicals (except for ethylene) has fallen. In absolute and percentage terms, production of propylene, benzene, and butylene have fallen the most. There are various factors behind this trend.

One factor is the closure of petrochemical facilities over the last decade in Ontario and Québec, including refineries, steam crackers and polymer production units. Closure of refineries leads to decreased levels of propylene and benzene production. Closure of the Petromont facility, which used primarily heavy feeds, not only reduced overall ethylene production but also co-product supply.

Furthermore, as gasoline production in Canada has decreased over the last decade (driven by lower demand), given that a large portion of benzene is used for gasoline blending, demand for benzene, and thus, production, has declined.[41]

Lastly, CERI estimates that the largest share of petrochemical production in Canada comes from steam crackers. Therefore, an increase in ethylene production and a decrease in co-product production points to a shift to lighter feedstocks at the ethylene crackers (Figure 1.4, bottom).

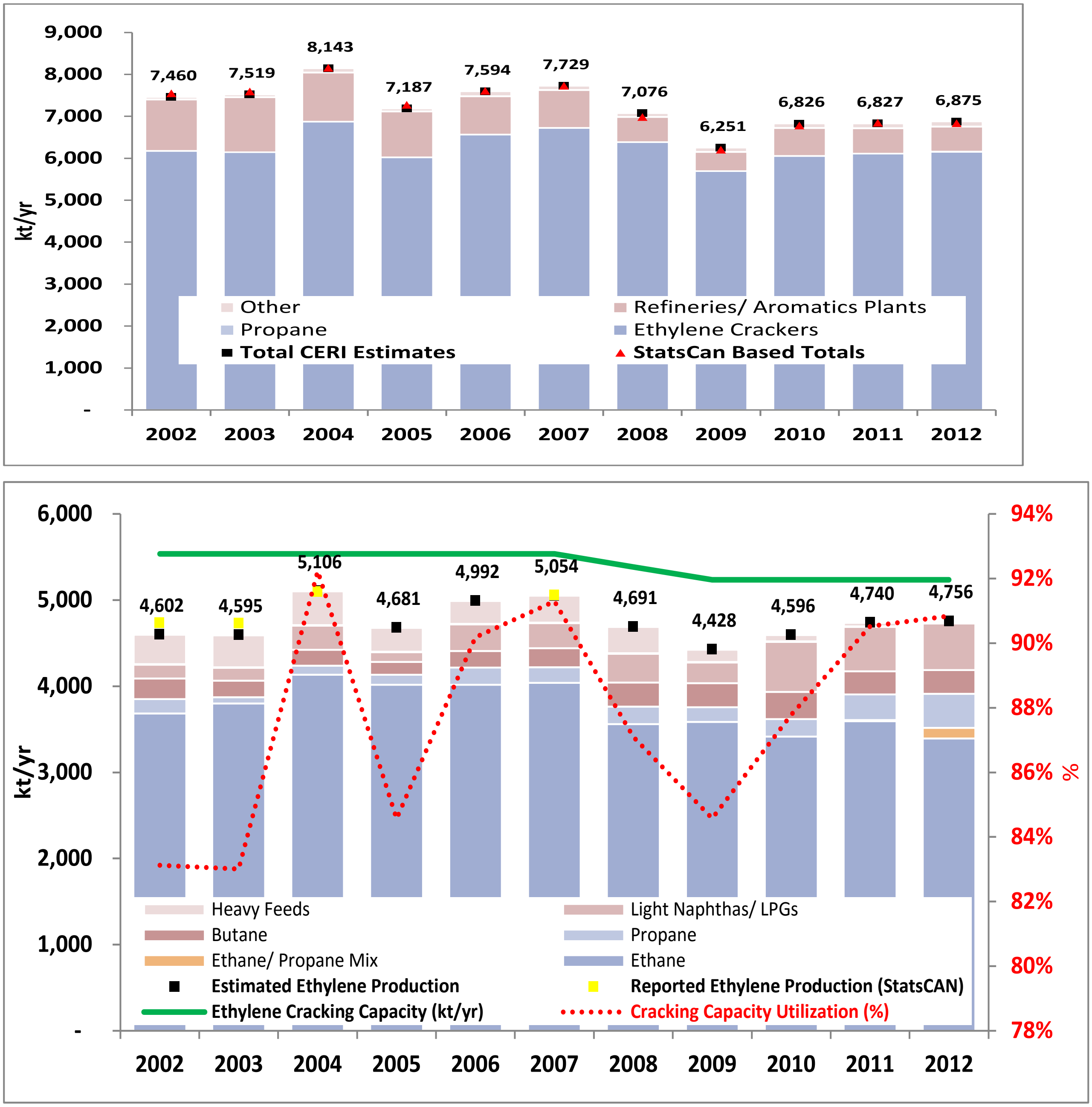
This trend is expected to continue as the Sarnia steam crackers continue to shift to a lighter feedstock, resulting in lower output volumes of co-products and possibly affecting co-product derivative users' operations.

CERI estimates that in 2012 approximately 89 percent of the petrochemicals were produced by steam crackers, 9 percent by refineries (aromatics plants), and 2 percent by other plants[42] (Figure 1.5, top).

It can also be observed that ethylene cracking capacity utilization has improved over the last few years (Figure 1.5, bottom), and if this trend is to continue, future expansions in ethylene cracking capacity and derivative plants can be expected.

[40] ICIS, Canada Petromont closure "a major loss": http://www.icis.com/Articles/2008/02/13/9100564/canada-petromont-closure-a-major-loss.html
[41] There is an 86 percent correlation between gasoline production and benzene production levels (2002 – 2012)
[42] Primarily PGP and butylene from the Williams fractionator

Figure 1.5: Total Petrochemical Production in Canada by Source (Top), and Estimated Ethylene Production from Steam Crackers by Feedstock (Bottom) (kt/yr) (2002 - 2012)



Source: CERI estimates with data from Industry Canada, and Statistics Canada. Figures by CERI

Chapter 2: The Petrochemical Industry's Contribution to the Canadian Economy

This section provides statistics such as gross domestic product (GDP), employment, wages, output and taxation, etc. in order to quantify the contribution of the petrochemical industry to the Canadian economy.

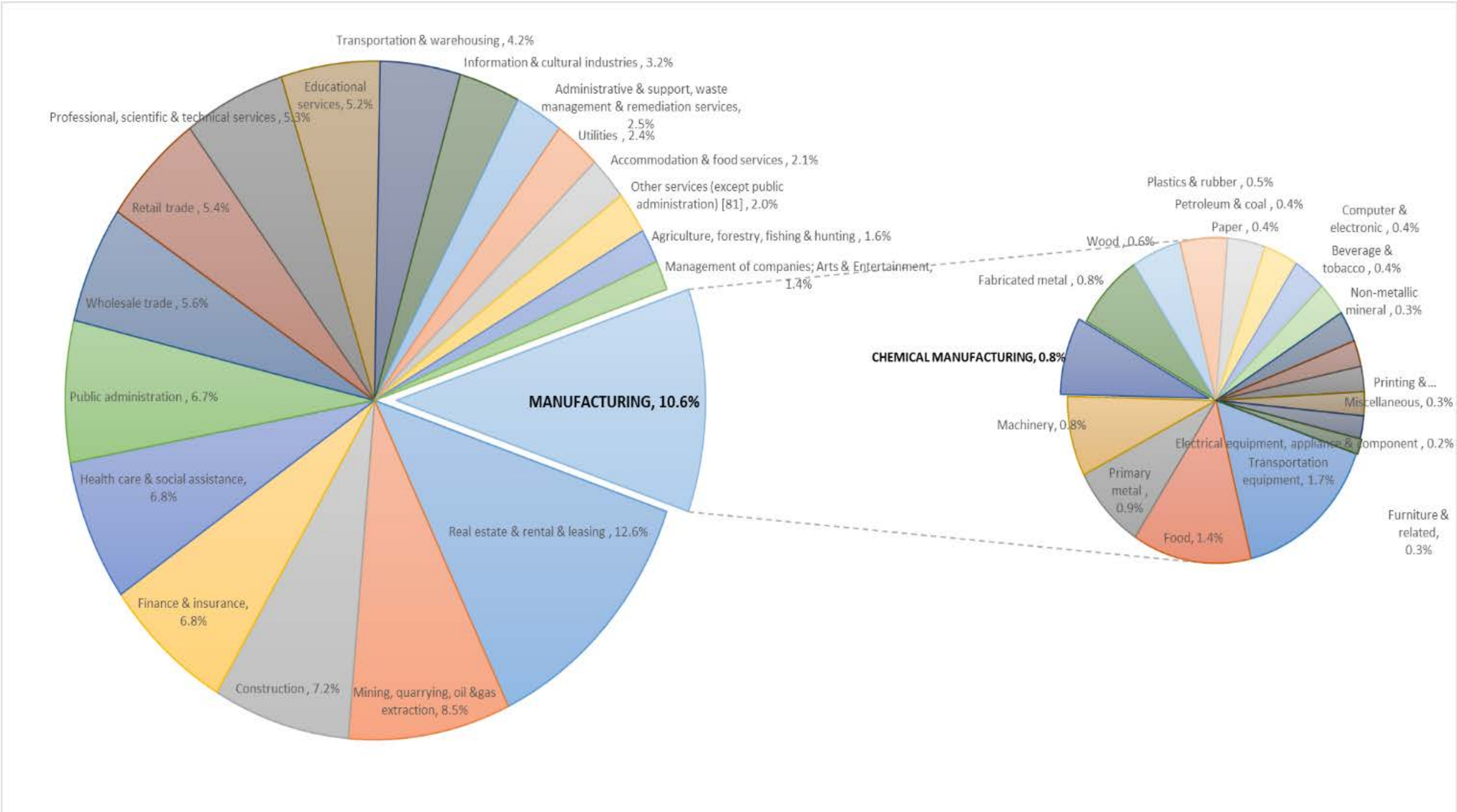
Canada's gross domestic product at basic prices was around 1.7 trillion dollars for the year 2014. When classified by the North American Industry Classification system (NAICS) in the Statistics Canada database, the chemical manufacturing sector contributed 13.4 billion dollars and made up 0.8 percent of the GDP contribution to the Canadian economy.

The chemical manufacturing sector makes a small but significant contribution, following closely behind transportation, food, and primary metal manufacturing which together contribute around 4 percent to the Canadian economy. This sector plays a crucial role in obtaining inputs from the oil and gas industry and providing outputs to the other sectors. The Chemistry Industry Association of Canada predicts a 30 percent growth of capital investments in 2015, up to $3.4 billion overall.

Figure 2.1 shows the contribution of the Chemical Manufacturing Sector to the Canadian Economy for the year 2014 and includes a comparison against other Canadian industries on a GDP contribution basis. The GDP values associated with the major sectors (4 percent or more contribution) are listed below.

- Manufacturing = $174 billion
- Real estate & rental & leasing = $205 billion
- Mining, quarrying, oil & gas extraction=$138 billion
- Construction = $117 billion
- Finance & insurance= $111 billion
- Health care & social assistance= $110 billion
- Public administration = $110 billion
- Wholesale trade= $91 billion
- Retail trade =$88 billion
- Professional, scientific & technical services= $87 billion
- Educational services= $84 billion
- Transportation & warehousing = $68 billion

Figure 2.1: Year 2014 Contribution of the Chemical Manufacturing Sector to the Canadian Economy and Comparison to Other Sectors (%2007$ billions)



Source: Statistics Canada CANSIM Table 379-0031

Chemical manufacturing (NAICS Code 325) lies within the manufacturing sector and consists of:

- basic chemical manufacturing [NAICS 3251],
- resin, synthetic rubber, and artificial and synthetic fibres and filaments manufacturing [NAICS 3252],
- pesticide, fertilizer and other agricultural chemical manufacturing [NAICS 3253],
- pharmaceutical and medicine manufacturing [NAICS 3254],
- paint, coating and adhesive manufacturing [NAICS 3255],
- soap, cleaning compound and toilet preparation manufacturing [NAICS 3256], and
- other chemical product manufacturing [NAICS 3259].

The industrial chemical industry consists of the first two major industries, namely basic chemical manufacturing [NAICS 3251], and Resin, synthetic rubber, and artificial and synthetic fibres and filaments manufacturing [NAICS 3252].

Provincial Breakdown: Ontario, Québec and Alberta

The Canadian petrochemical industry (NAICS 32511) had shipments of $7.8 billion in 2014, and employed 1,130 people in 26 manufacturing establishments. In 2014, exports of petrochemicals were $2.9 billion and imports were $1.2 billion.[43] Table 2.1 shows available statistics for the petrochemical manufacturing sector from Industry Canada.[44]

Table 2.1: Petrochemical Manufacturing (32511) Statistics

PETROCHEMICAL MANUFACTURING (NAICS 32511) STATISTICS	SOURCES: STATISTICS CANADA, INDUSTRY CANADA
Number of establishments 2013	Alberta:10 ; Nova Scotia:1; Ontario: 7; Québec:7; Total Canada:25
Employment by type of employee 2012	Production: 882; Administration: 304; Total:1186
Average annual salaries	Production:$107,836 ; Administration:$78,016
Total salaries and wages	Production:$95.1 million ; Administration: 23.7 million
Manufacturing revenues 2012	$7.2 billion
Manufacturing value added 2012	$1.9 billion
Manufacturing costs by category	Materials & supplies: $5 billion; Energy, water & vehicle fuel: $276.8 million; Production worker wages: $95.1 million
Manufacturing revenue per employee	$6.0 million
Manufacturing revenue per employee	$1.6 million

[43] Statistical Review by Chemical Industry Association of Canada 2014- Petrochemicals
[44] Industry Canada: https://www.ic.gc.ca/app/scr/sbms/sbb/cis/internationalTrade.html?code=32511&lang=eng

Most petrochemical plants are located near oil producing and oil refining centers or near natural gas sources and transmission pipelines, with a concentration of plants in Ontario, Québec and Alberta.[45] Table 2.2 shows the comparison between the different provinces in terms of percentage of the total composition of the provincial chemical industry that belongs to the industrial chemical industry (NAICS 3251 & 3252), value of shipments, and trade for the industrial chemical industry (NAICS 3251 & 3252) by province for the year 2014.

In Ontario, the largest industrial chemical industry (NAICS 3251 & 3252) cluster is located in the Sarnia region, while the next largest concentrations are in the Golden Horseshoe and along the St. Lawrence Seaway. Compared to all the Ontario manufacturing industries in 2014, the chemical sector ranked second in terms of exports; third based on shipments, value added and average salaries; and sixth based on employment.[46]

Québec has a smaller industrial chemical cluster (NAICS 3251 & 3252) compared to Ontario and Alberta, concentrated in the eastern end of Montreal and along the south shore of the St. Lawrence. Compared to the total of Québec manufacturing industries in 2014, the chemical sector ranked fourth based on shipments, and eighth based on employment[47].

Alberta has one of the largest refining and petrochemical industries in Canada and is the leading producer of petrochemicals. The two main industrial chemical clusters (NAICS 3251 & 3252) are located in the northeast of Edmonton and in central Alberta, near Red Deer. Compared to the total of Alberta manufacturing industries in 2014, the chemical sector ranked first in exports, average salary and value added; second in shipments, and fifth on employment.[48]

[45] http://www.thecanadianencyclopedia.ca/en/article/petrochemical-industry
[46] Statistical Review by Chemistry Industry Association of Canada 2015- Ontario
[47] Statistical Review by Chemistry Industry Association of Canada 2014- Québec
[48] Statistical Review by Chemistry Industry Association of Canada 2014- Alberta

Table 2.2: Percentage of Total Chemical Industry Composition, Value of Shipments, and Trade by Province for 2014

Year 2014	Ontario		Québec		Alberta	
Industrial chemicals	NAICS 3251	NAICS 3252	NAICS 3251	NAICS 3252	NAICS 3251	NAICS 3252
% of total chemical sector composition	26%	26%	37%	6%	46%	33%
	Total:52%		Total:43%		Total:79%	
Value of Shipments	$12.0 billion (42%)		$4.4 billion (19%)		$11.2 billion (39%)	
Imports	$10.9 billion		$4.0 billion		$1.5 billion	
Import regions	US (74%), China (4%), Switzerland (3%)		US (56%), China (5%) Germany (4%),		US (80%), China (8%), Mexico (2%)	
Exports	$8.0 billion		$2.6 billion		$7.5 billion	
Export regions	US (78%), UK (5%), China (4%)		US (85%), Mexico (4%)		US (81%), China (10%), Mexico (4%)	

Source: 2015 Statistical Review by Chemical Industry Association of Canada; Basic chemical manufacturing [NAICS 3251]; Resin, synthetic rubber, and artificial and synthetic fibres and filaments manufacturing [NAICS 3252]

Economic Analysis

The total contribution of the petrochemicals sector to the Canadian economy is measured from a macroeconomic perspective, with the petrochemicals industry activity included as an input cost of the value of domestic production. To fully understand these economic benefits, Statistics Canada 2009 Input, modified basic price set of input/output tables is employed.

The gross domestic product or value added is a measure of the unduplicated production of an industry and does not include the intermediate costs of goods and services purchased from other industries. The "use" matrix displays all the intermediate costs incurred in production by an industry plus the indirect taxes and subsidies, and returns to the factors of production, namely: wages and salaries, supplementary labour income, mixed income and operating surplus. Calculating an industry's GDP at basic prices is the sum of its incomes (wages and salaries, supplementary labour income, mixed income and other operating surplus) plus taxes less subsidies on production.

CERI estimated that the petrochemicals sector consisted of 78 industries that generate goods and services that are employed in the exploration and development of oil and gas resources. To determine the contribution of the petrochemicals sector, all of the activities within the NAICS Code BS325100-basic chemical manufacturing were included in the analysis.

According to the Statistics Canada 2009 input/output tables, in 2009, the petrochemicals sector contributed $3.9 billion dollars to the economy. Basic chemical manufacturing (BS325100) contribution was $2.4 billion dollars, and the resin, synthetic rubber, and artificial and synthetic fibres and filaments manufacturing (BS325200) contribution was $1.4 billion dollars.

The same level of aggregation tables are not available for the year 2014. When retrieved directly from the Statistics Canada database for the year 2014,[49] the petrochemicals sector shows a contribution of $4.7 billion dollars[50] to the Canadian economy. Basic chemical manufacturing contributed $2.7 billion dollars and the resin, synthetic rubber, and artificial and synthetic fibres and filaments manufacturing contributed $1.9 billion dollars. This represents around a 20 percent increase in the petrochemicals sector contribution to the Canadian economy from the year 2009 to 2014. The approximate tax contributions for basic chemical manufacturing in 2014 are ($ million):

- Federal income tax – 31.6
- Provincial Income Tax – 13.2
- Corporate Tax – 514.6

[49] CANSIM Table 379-0031
[50] chained 2007 dollars

Chapter 3: Feedstock Availability and Market Dynamics

The purpose of this chapter is to highlight the availability of surplus (to domestic market needs) production volumes of gas and NGLs as potential petrochemical feedstock. The continued expected supply increases of these commodities (NG/NGLs), evolving domestic demand dynamics, and shrinking export markets in the US, highlights a need to develop new domestic demand sources, or to develop other export markets.

This section focuses on quantifying how much of each commodity can be made available to the petrochemical industry as a feedstock, to determine if there is a case for investment. As discussed, there are enough volumes for a given set of investments, such as various methanol/ammonia or fertilizer manufacturing facilities, an ethylene cracker, and potentially one or two PDH plants. This finding would also lead to the conclusion that this is not necessarily a new situation in Canada, but perhaps one that looks increasingly viable given the future outlook.

Canadian NGLs Overview and Outlook

The following sections describe the model methodology, results of the Canadian supply and demand, historical and future outlook, and potential feedstock competition for natural gas, ethane, propane, and butane in Canada[51].

Model Methodology

The CERI gas forecast model is designed to convert provincial well activity forecasts to a natural gas and natural gas liquids forecasts. This process involves utilizing historical data to determine base line production parameters (initial production rates, decline rate, compositional makeup, and gas plant design) linked to a representation of the physical gas transmission system connecting supply to demand. Between supply and demand, the model accounts for liquids recovered at field gas plants and straddle plants along with deliveries to domestic meter stations (major cities and grouped rural locations), fuel used in the transport system and volumes delivered to export locations.

This model utilizes the physical description of the gas transmission systems (Nova Alberta pipeline system, TransCanada pipeline system, Spectra pipeline system) and subdivides these pipelines into PIA areas (Pipeline Influence Areas). PIA's are a group of receipt points between compressor station locations, divergent or convergent pipeline locations, major off-take locations (cities) or export point. This is done to facilitate the volume recovery at the straddle

[51] For further information please refer to CERI study Western Canada Natural Gas Forecasts and Impacts (2015-2035): http://ceri.ca/images/stories/Study_149_-_WCSB_Natural_Gas_Forecasts_and_Impacts_-_July_2015_final.pdf

point locations or the compositional makeup (energy content) of streams delivered for domestic consumption. In addition to PIA areas, special attention is paid to geological formations ("PIA-Form") that have or are about to attract industry attention. Examples of this include the Montney (British Columbia and Alberta), Duvernay (Alberta), Wilrich (Alberta), and Bakken (Saskatchewan). Data for these special elements are identified by a reference to the formation code and the closest PIA area.

The model then utilizes an iterative procedure to determine the provincial well drilling (on a year-by-year basis) that will deliver sufficient natural gas to the domestic market, export market and all uses and losses on the transmission system. Output from the model is in the form of upstream wellhead supply, gas plant recoveries and losses (fuel and volume shrinkage) component makeup of the gas stream at various locations on the pipeline, recoveries at the straddle plants and energy delivered to markets.

The model relies heavily on public information from various sources to determine the basic parameters used in establishing the initial model framework. Sources for this information include:

1. The Alberta Energy Regulator (AER)
2. Saskatchewan Energy and Mines (SEAM)
3. The British Columbia Oil and Gas Commission (BCOGC)
4. The National Energy Board of Canada (NEB)
5. Canadian Association of Petroleum Producers (CAPP)
6. Petroleum Services Association of Canada (PSAC)

The three provincial regulators provide detailed well information coupled with the complete historical (month-by-month) list of produced fluids (natural gas, crude oil, bitumen, coalbed methane, condensate and water) on a well-by-well basis. In addition, data pertaining to the individual well configuration as to its finish drilling date, initial production date, major production fluid (oil, gas, coalbed methane, bitumen, etc.), original status, current status, total depth, true vertical depth and physical locations.

These individual well records are linked to either the individual well raw gas compositional analysis (methane, ethane, propane, butane, pentanes, hydrogen sulphide, carbon dioxide and others) or if that is unavailable, an average pool analysis. Relying on the most recent month and year, the model can be calibrated as to natural gas liquids recovered, composition and heating value and points on the pipeline system, recoveries at straddle plants and deliveries to domestic off-take points and export border points.

This information is utilized to determine: the average initial production rate (peak month of production in the first 3 months of production), annual production by year, first production date, and last production date (if abandoned). Monthly production is used to determine the historic decline curve for all wells within a given study area that commenced production in a given year. A series of harmonic and exponential curves are investigated to establish a representative "Type" decline curve for a given study area. This process is replicated for vertical and horizontal wells separately.

The “Type” curve is used to establish the decline path for wells that are currently on stream; based on the average number of months the existing operating wells have been operating. The average on stream months defines the starting point on the “Type” curve where the production rate will be for the forecast months. This same curve starting at time zero is used to define the production path for new wells drilled and connected in the future.

At the completion of the iterative procedure, the model describes the number of wells drilled by PIA or PIA-Form group, the annual wellhead production, the component stream, the recovered components by plant, deliveries (volume and composition) to domestic points and export points and the composition of the flow stream at several points on the transmission system. This information is processed to determine capital requirements for the drilling program, gross and net gas flows, natural gas liquids recovered, Sulphur recoveries, condensate recoveries and pentanes (C5, C6, C7, etc.) recoveries.

Natural Gas Supply and Demand

For the North American analysis, CERI collaborated with ICF International to update the 2013 Natural Gas Pathways base case and generate three LNG scenarios utilizing ICF’s Gas Market Model. ICF International’s Gas Market Model (GMM®) is a general equilibrium model representation of gas markets throughout the US and Canada, with Mexican gas production and consumption currently modeled at four border crossing points. GMM® is used to evaluate the marginal value of natural gas prices at different market centers under base case and alternative scenarios; inter-regional flow volumes and the future value of pipeline capacity; and storage activity and value at different market centers.

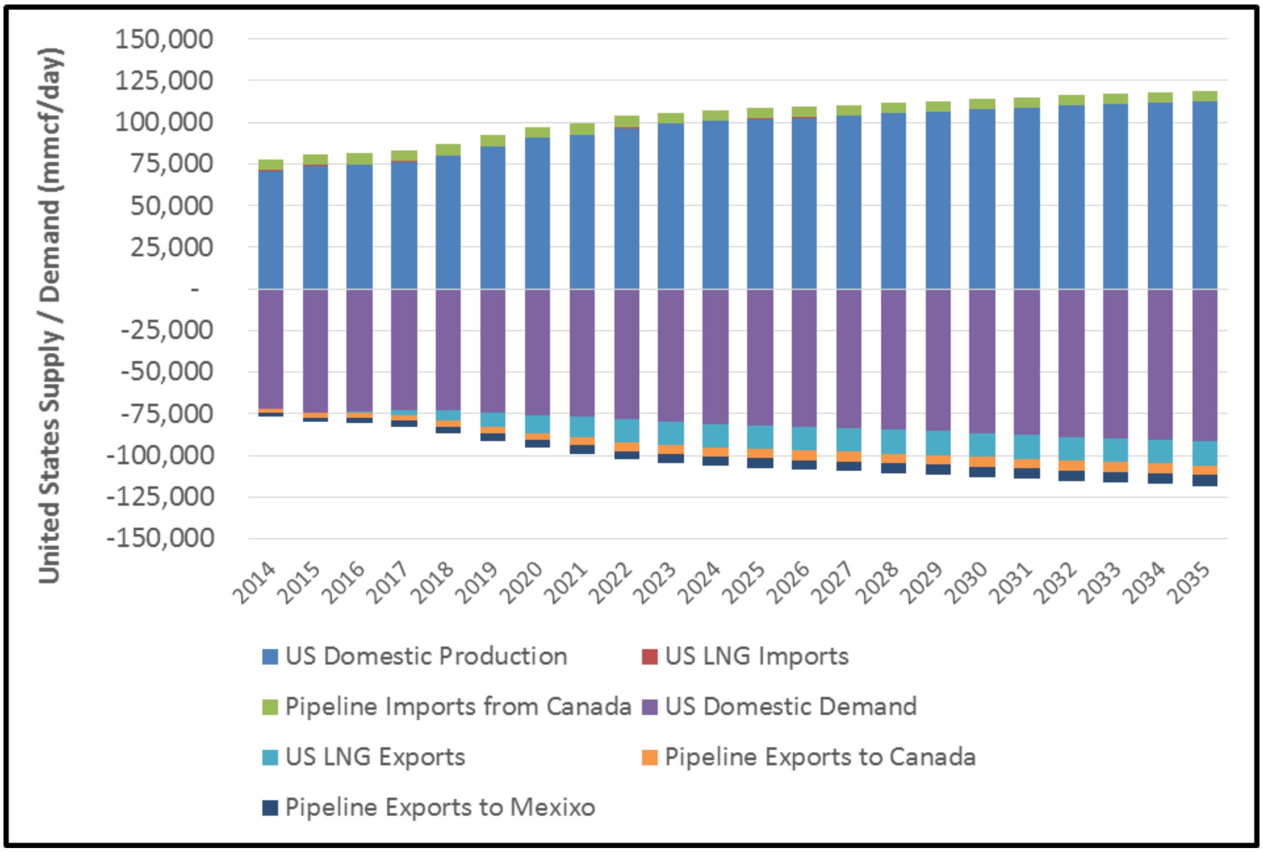
For western Canadian well developments, the CERI gas forecasting model was utilized. The linkage between these two models is the GMM calculated annual flow volume requirements on the Canadian export pipelines including Gas Transmission Northwest, Northern Border, Alliance, Spectra BC, Iroquois Pipeline, Great Lakes Gas Transmission and others. These export requirements are added to the western Canada domestic demand, eastern Canada net domestic demand (minus imports from the US) and BC LNG exports to equal the annual demand requirements. CERI’s gas forecast model determines the number of wells required to balance supply and demand and estimates the region within the three western provinces where these wells could be drilled and determines the initial production rates and decline curve that could be anticipated from these wells in the future. Figure 3.1 details the United States supply/demand balance, as part of the North American gas market forecast, based on the ICF GMM® base model (Q4 2014) including the following LNG assumptions:

- 13 bcf/day of LNG exports from the Gulf of Mexico
- 4.8 bcf/day of LNG exports from British Columbia, Canada
- 1 bcf/day of LNG exports from Cove Point, Maryland
- 2 bcf/day of LNG exports from Atlantic Canada

The inclusion of these LNG assumptions determined the CERI LNG January 2015 North American case. Based on this view, the United States domestic production is forecasted to grow from the current level of 71 bcf/day (25.9 tcf/year) to 112 bcf/day (41.2 tcf/year) by 2035. Led by the Marcellus developments, this growth equates to 43 percent growth in domestic supply over the next 12 years. The total US supply is augmented by pipeline imports from Canada that will continue to decline from the current 7.2 bcf/day to 6.2 bcf/day by 2025 and remain at that level to the end of the forecast.

Pipeline imports of US natural gas into eastern Canada will grow from the current level of 2.6 bcf/day to 6.0 bcf/day by the end of the forecast. Canada will remain a “net” pipeline exporter (exports to US minus imports from the US into Canada) for the duration of the forecast albeit by less than 0.5 bcf/day by the end of the forecast. Ontario, Québec and Atlantic Canada imports of natural gas from the US will expand from 2.6 bcf/day to 6.1 bcf/day over the next 12 years, which effectively backs western Canada gas out of these markets. Part of this increase in demand is the assumption that 2 bcf/day of LNG exports will be developed in Atlantic Canada. While US domestic demand displays minimal growth, from 71.7 bcf/day to 81.6 bcf/day, exports to Mexico, exports of LNG to global markets and pipeline exports to Canada, in total, show a growth from 4.5 bcf/day to 25.7 bcf/day over 12 years.

Figure 3.1: United States Supply/Demand Balance (2014-2035)

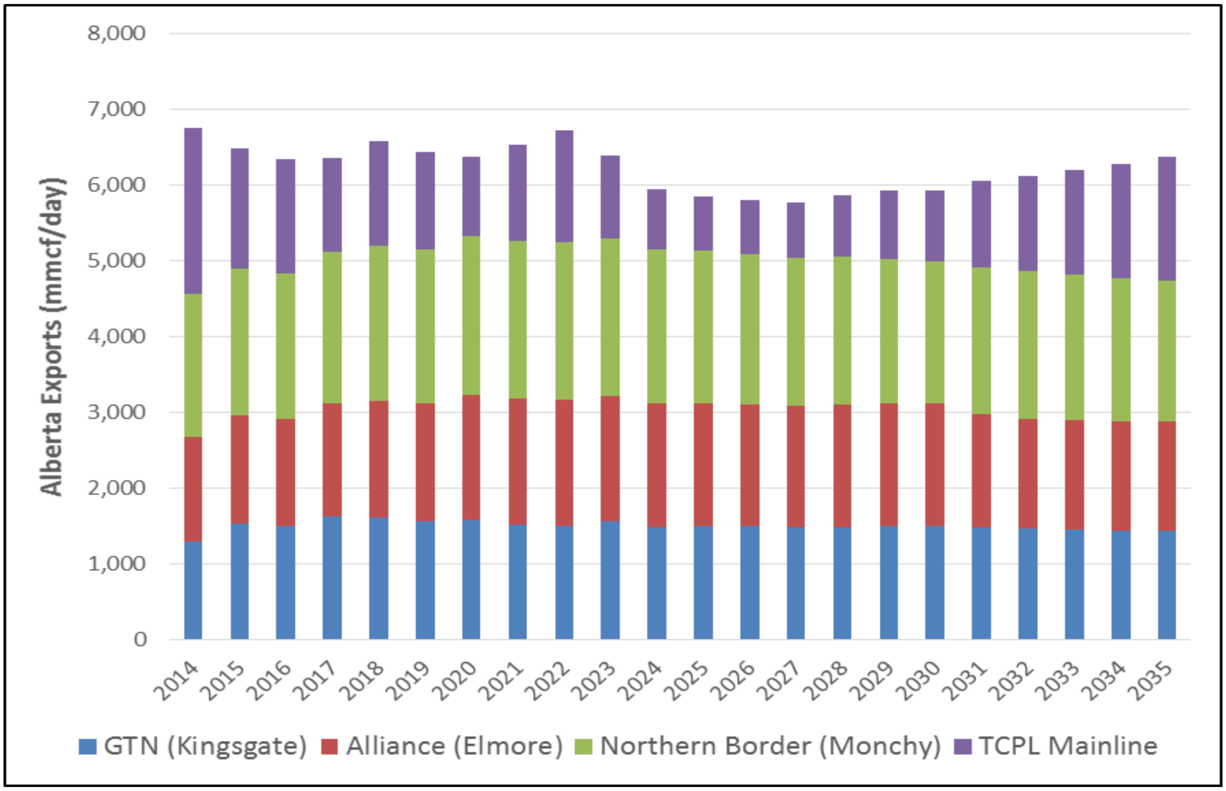


Source: ICF International, CERI

Alberta

Figure 3.2 illustrates the forecast of export volumes for the four major export pipelines leaving Alberta: the Gas Transmission Northwest Pipeline (GTN) to California, the Alliance Pipeline (Alliance) to Illinois, the Northern Border Pipeline (NBPL) to Illinois, and the TransCanada Mainline (TCPL Mainline) connecting Alberta to eastern Canada and the eastern seaboard of the United States. The results from the Case 2 North American forecast[52] would suggest that for the length of the forecast the annual average flows for the GTN pipeline will stabilize at the 1,500 mmcf/day level, NBPL will experience flow levels varying between 1,900 and 2,100 mmcf/day, and Alliance will grow slightly from 1,400 to 1,650 mmcf/day. However, the real story surrounds the TCPL Mainline, which is forecasted to continue its decline that started in 2010 and averaging 1,600 mmcf/day in 2015, heading to 600 mmcf/day by 2025 before experiencing a recovery back to the 1,500 level by the end of the forecast.

Figure 3.2: Alberta Exports to the United States and Eastern Canada (2014-2035)

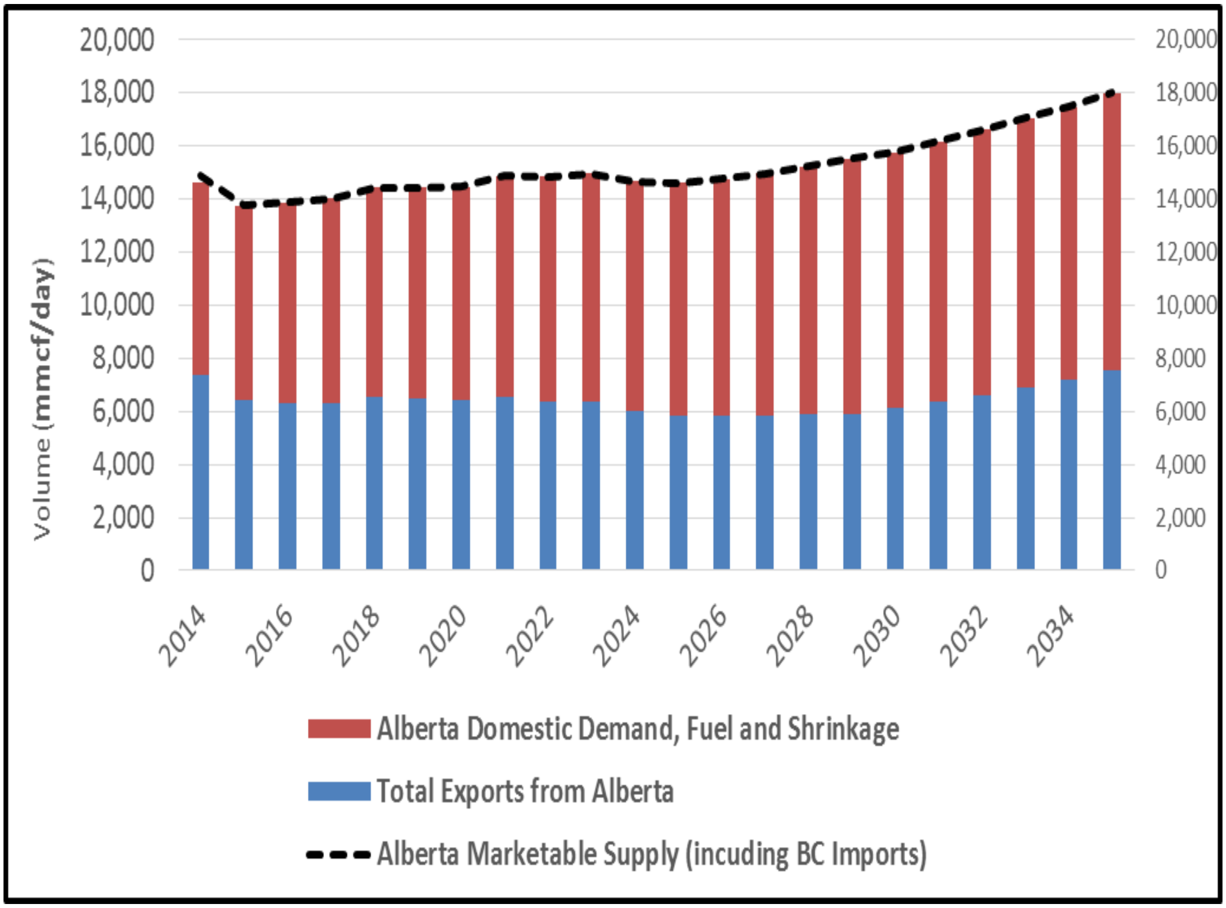


Source: ICF International, CERI

[52] CERI Study 138, North American Natural Gas Pathways, June 2013

Figure 3.3 indicates that the future demand for natural gas will change from a 50:50 split between export volumes and internal use volumes (residential, commercial, industrial, pipeline fuel and losses and straddle plant shrinkage) to a 60:40 split because of declining exports and increasing internal demand.

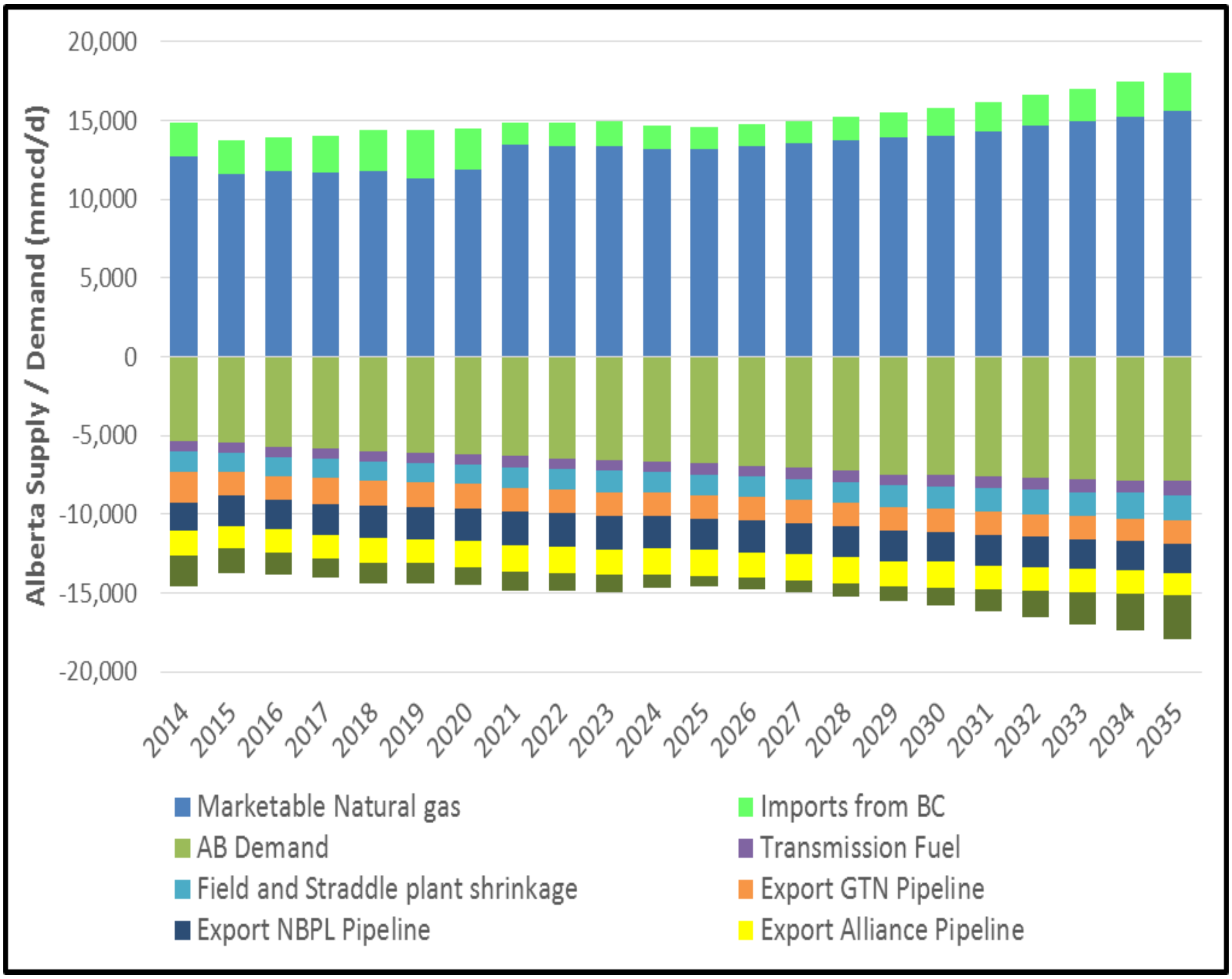
Figure 3.3: Alberta Natural Gas Exports and Internal Requirements (2014-2035)



Source: AER, NEB, CERI

Figure 3.4 details the breakdown of the elements that define the annual Alberta supply/demand relationship. As it relates to this figure, imports from British Columbia are added to the Alberta-sourced supply and Alberta supplies are considered as wellhead volumes from which liquids are extracted in the field and at the straddle plant locations (shrinkage). Transmission fuel and losses is considered field processing, gas plant fuels and transmission fuels.

Figure 3.4: Alberta Supply/Demand (2014-2035)



Source: AER, NEB, CERI

British Columbia

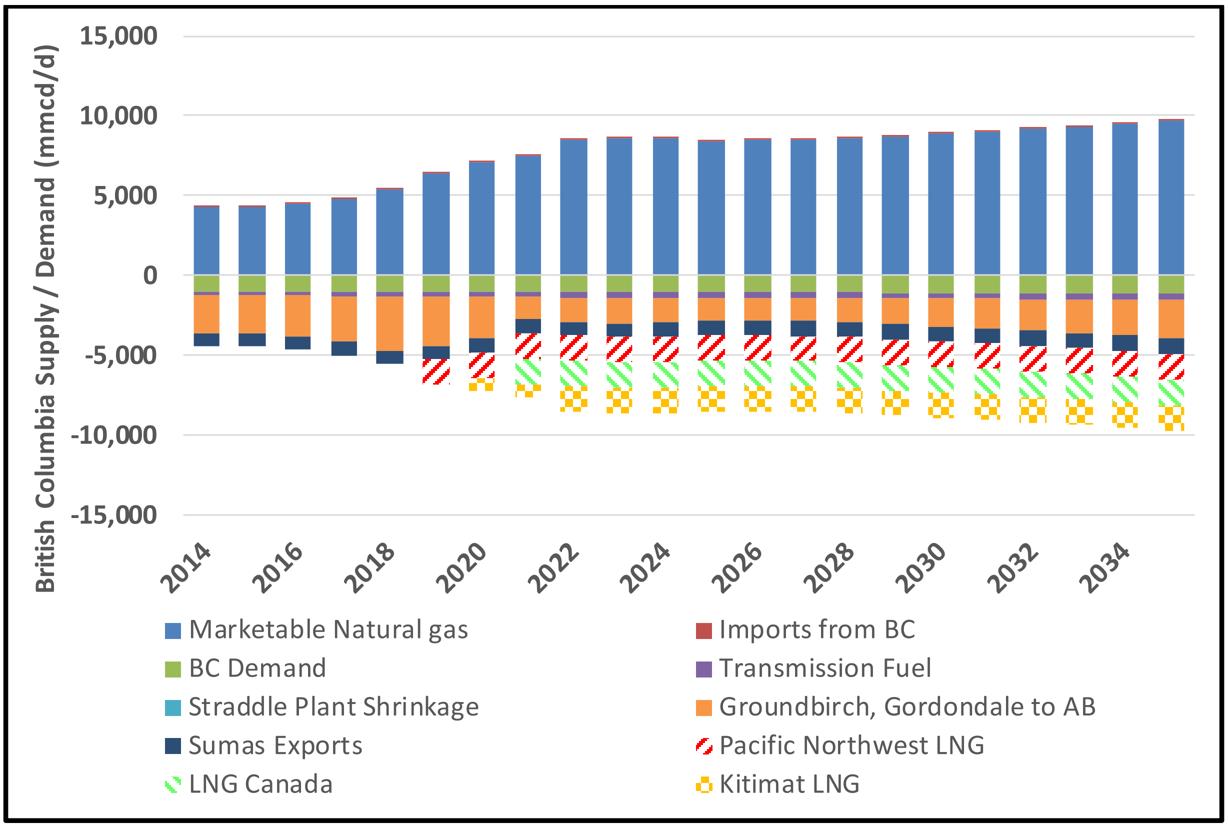
For the past three years, the Montney formation has been the focus of upstream developments for British Columbia. In fact, in excess of 84 percent of the newly licensed gas wells in BC over the period January 2012 to December 2013 have been to explore the Montney formation. CERI has determined that on a supply cost basis the Montney is ranked among the top shale gas deposits in North America from a productivity, NGL content and economic point of view.

However, the industry fascination with the Montney formation is as much about its proximity to the proposed LNG terminals as it is to the resource potential metrics.

As in the case of Alberta competing against the Marcellus for market share, northeastern British Columbia must compete against Alberta, and flow through Alberta, in order to access the larger United States markets. Currently, natural gas from northeastern British Columbia has three demand points, the lower mainland (Vancouver), the I5 corridor in Washington State and connection to the TCPL/NOVA system via the Groundbirch/Gordondale laterals.

Figure 3.5 suggests that the BC domestic demand and the export to the United States at Sumas (I5 corridor) will expand at the rate of about 15 mmcf/day/year. This is relatively small when compared to the proposed LNG projects that could see incremental growth of between 3,000 to 5,000 mmcf/day. With respect to this report, it has been assumed that three terminals will be constructed totaling 5,400 mmcf/day capacity operating at an annual average volume of 4,800 mmcf/day. The three terminals are indicated on Figure 3.5 as the red, green and yellow hatched bars.

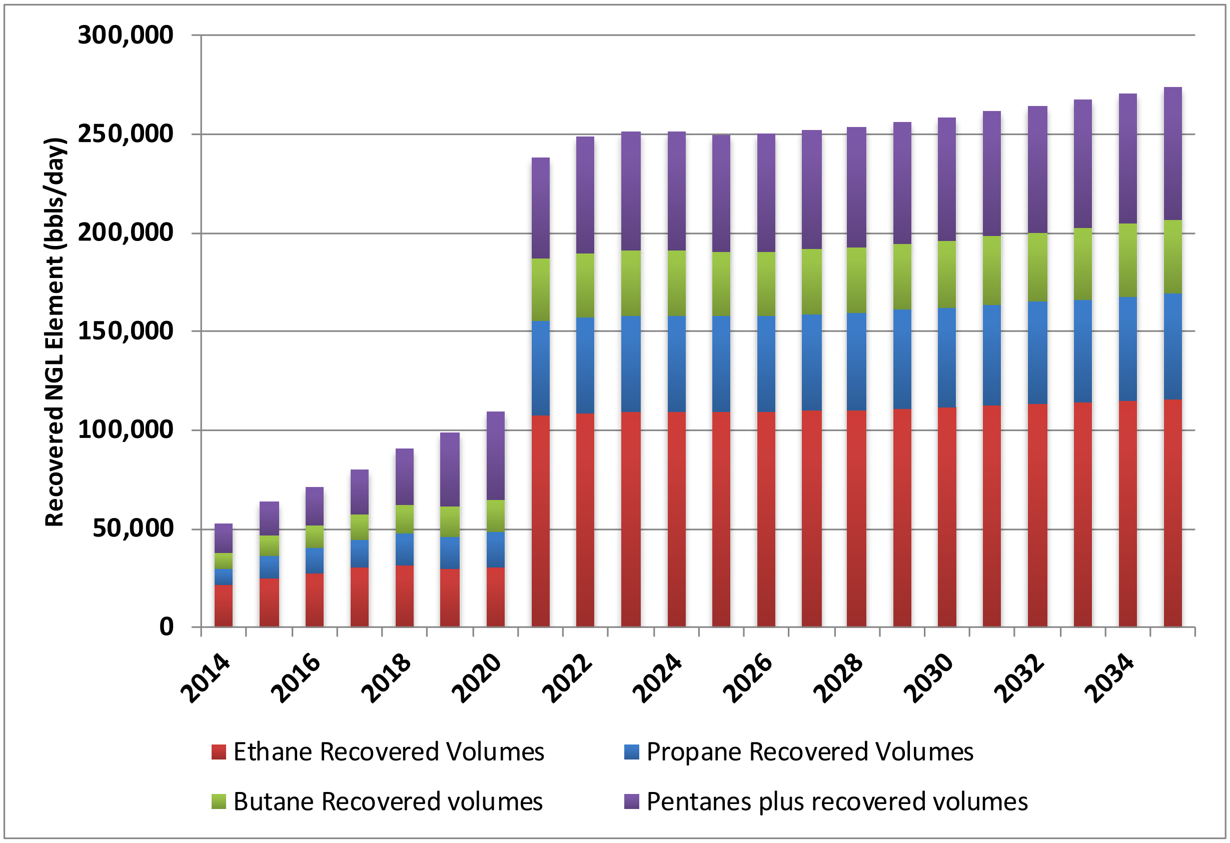
Figure 3.5: British Columbia Supply/Demand (2014-2035)



Source: CERI

Each producing area and formation is connected to a reserves weighted average component structure and modeled as to the type of field plant operation (shallow or deep cut). The marketable gas (exit of the area plant) is connected to a nodal representation of the Spectra transmission systems so that area plant recoveries can be determined. The total of field plant recovered NGLs (spec product or mix steam) and the straddle plant recoveries are represented in Figure 3.6.

Figure 3.6: British Columbia NGL Recoveries by Field Plants (2014-2035)



Source: CERI

Ethane Supply and Demand

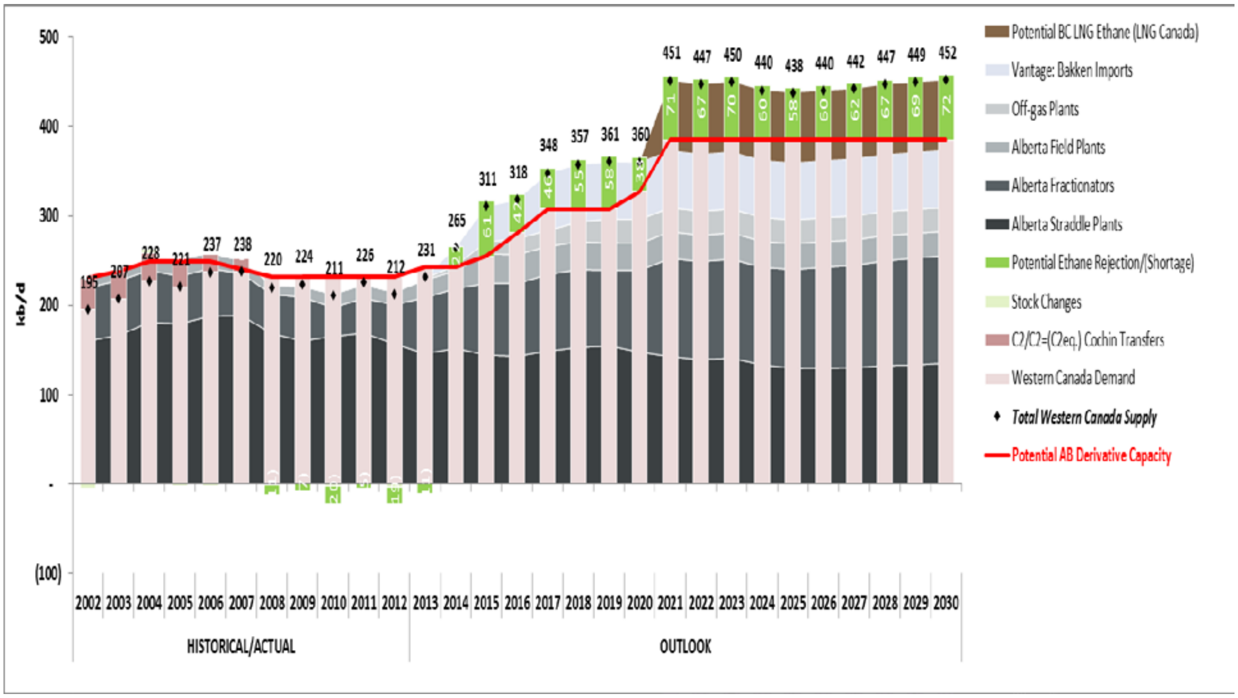
Figure 3.7 shows the ethane supply and demand balance, historical data and outlook to 2030 as determined by the CERI model. The demand elements includes feedstock, domestic demand, export, and potential ethane rejection or over supply values, which are obtained from various sources. The sources of supply and total Western Canada supply are illustrated in the figure. For market details and dynamics, please refer to the CERI NGLs in North America study: An update Part III- Market Fundamentals May 2014.[53] While the capacity of Alberta's straddle plants is forecasted to decline, the capacity of Alberta's fractionators will rise gradually in the future. Around the year 2021, Western Canada demand is forecasted to increase along with the potential

[53] http://ceri.ca/images/stories/2014-05-06_CERI_Study_139_Part_III.pdf

BC LNG ethane increases, therefore leading to an increase in the total supply of ethane. This oversupply situation is forecasted to result in the occurrence of a higher level of ethane rejection.

Canada imports from the United States increased noticeably when the Vantage Pipeline was commissioned in May 2014. A major portion of such Canadian imports is ethane, imported by pipeline into Alberta and Ontario.[54]

Figure 3.7: Ethane Supply and Demand (2002-2030)



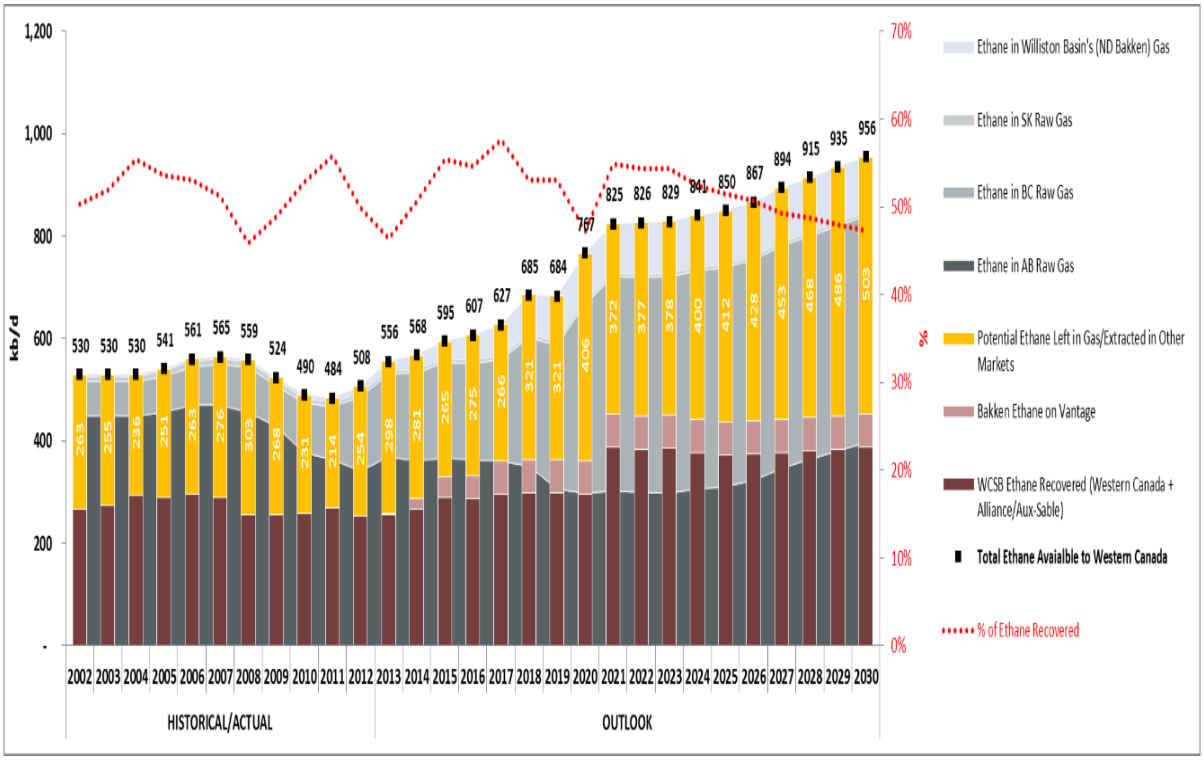
Source: CERI

It is estimated that in 2015, 52 percent of all ethane available to western Canada (WCSB + Bakken) will be extracted. That means about half of the available ethane is being left in the gas stream. Figure 3.8 shows the Western Canada's ethane supply model, which includes historical data and outlook to 2030. The supply geographic locations include ethane in Williston Basin's (ND Bakken) gas, Saskatchewan gas, British Columbia gas, Alberta gas, Bakken ethane on vantage, and finally the potential ethane left in gas/extracted in other markets or WCSB ethane recovered.

The percent of ethane recovered declines from the year 2015 onwards, but rises in 2017, falling again in succeeding years until the year 2020. However, the total supply of ethane available to western Canada is forecasted to increase over time. Most ethane availability growth is projected to arise from BC gas through LNG projects. Further, ethane could also be extracted in the WCSB via gas streaming, new straddle plants or LNG ethane extraction, which highlights the importance of both extraction and end-use infrastructure.

[54] http://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/snpsht/2015/08-05xprtsnrth-eng.html

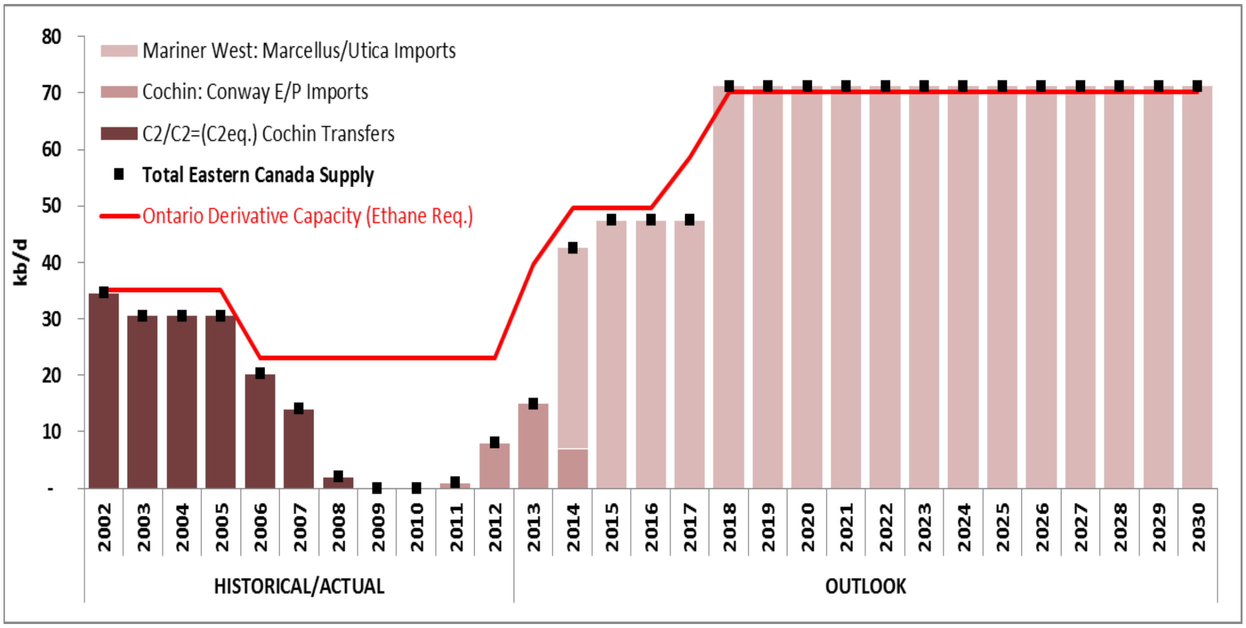
Figure 3.8: Ethane Supply Forecast for Western Canada (2002-2030)



Source: CERI

Figure 3.9 represents the supply of ethane in eastern Canada through imports and transfers, which includes historical data and outlook to 2030. From the year 2015, Mariner West: Marcellus/Utica imports are forecasted to be the only source of ethane supply in eastern Canada. Ontario's ethane requirements increase steadily from the year 2016-2018, after which they stabilize at 70kb/d to 2030.

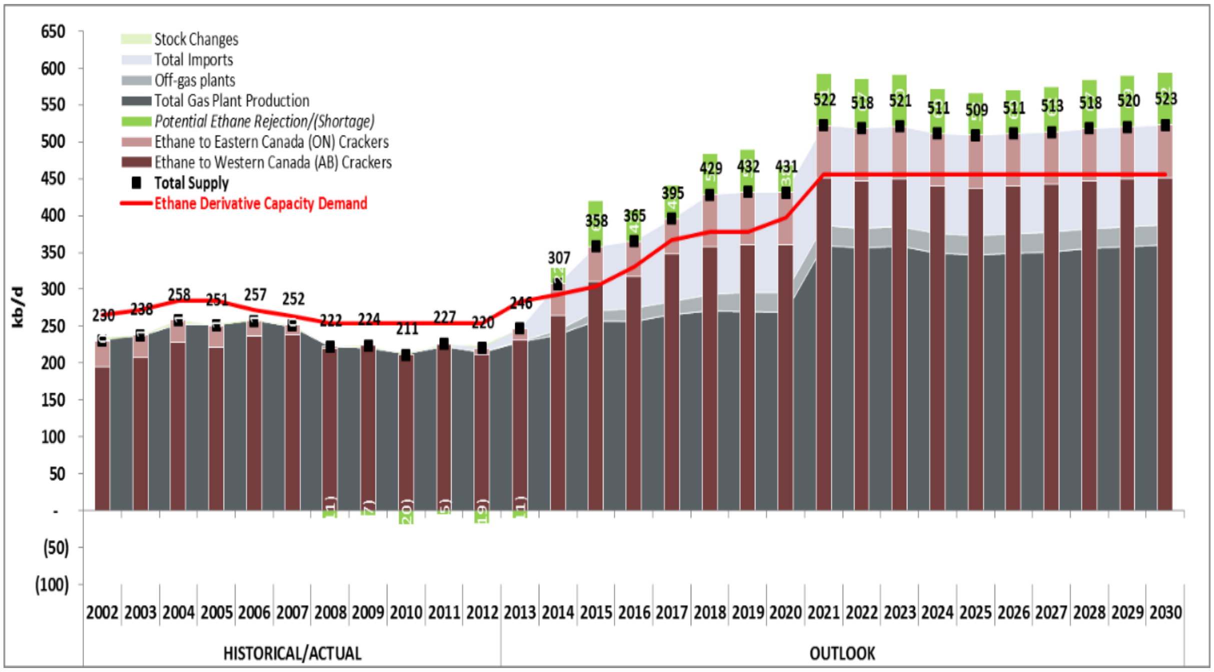
Figure 3.9: Eastern Canada's Ethane Supply (2002-2030)



Source:CERI

The historical data and forecast of ethane supply and demand in both Eastern and Western Canada is demonstrated in Figure 3.10. From 2013 onwards, ethane imports increase rapidly accompanying a rise in ethane derivative capacity demand and ethane to Canadian crackers. The potential ethane rejection in Canada rises to 2021 and remains stable through 2030.

Figure 3.10: Canada's Ethane Supply and Demand (2002-2030)



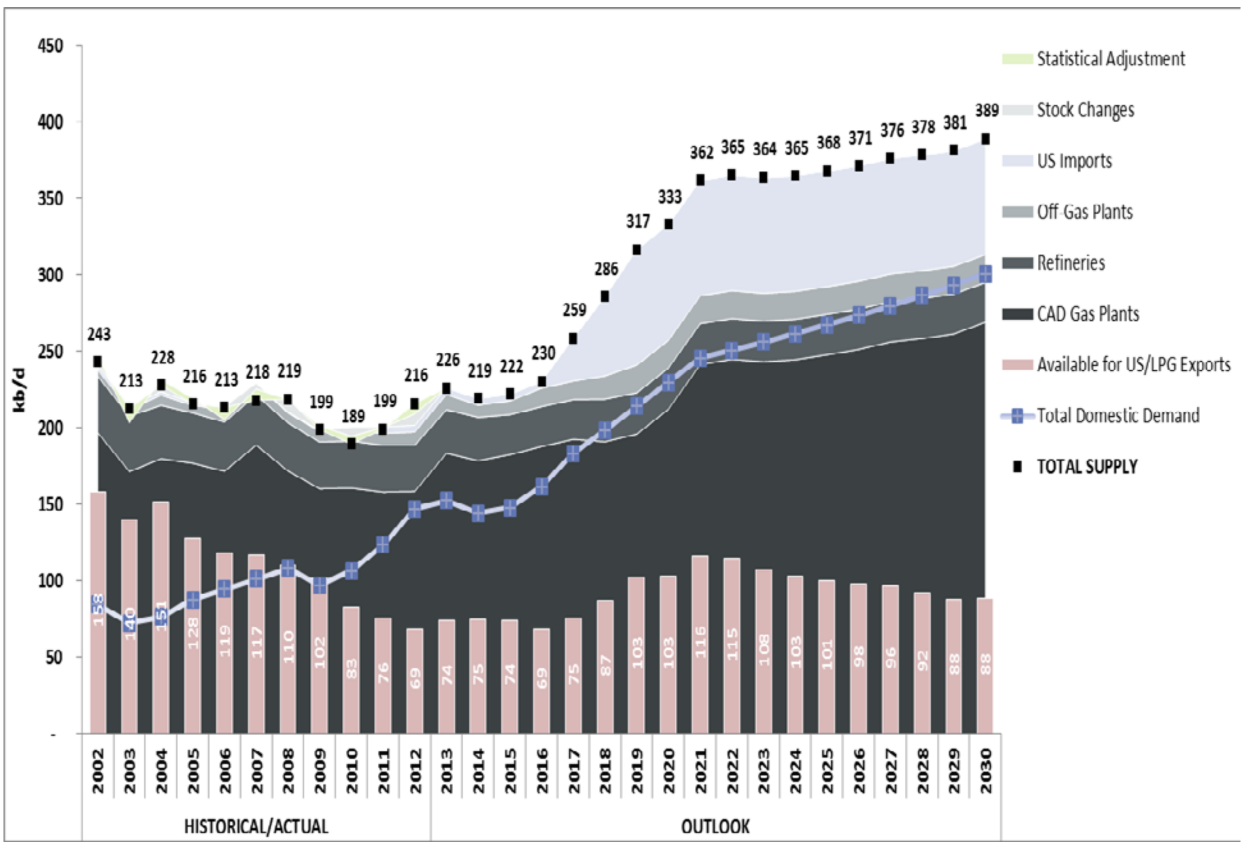
Source: CERI

Propane Supply and Demand

Figure 3.11 shows the propane supply and demand historical data and outlook to 2030 as determined by the CERI model. The demand elements include non-energy demand, retail energy demand and wholesale energy demand. The supply side is primarily consists of propane produced by gas plants, propane produced by refineries, off-gas plants, stock changes, and imports. Both supply and demand are forecasted to increase steadily over time.

While total Canadian propane production exhibited an overall declining trend until 2010[55] (at which point the trend reversed), domestic demand increases almost uninterrupted[56] between 2002 and 2030 kb/d. Canada currently exports all its surplus propane to the United States.[57] Exports to the US decline in 2012, 2016, and 2029. However, imports from the US increase from 2017 to 2030.

Figure 3.11: Propane Supply and Demand (2002-2030)

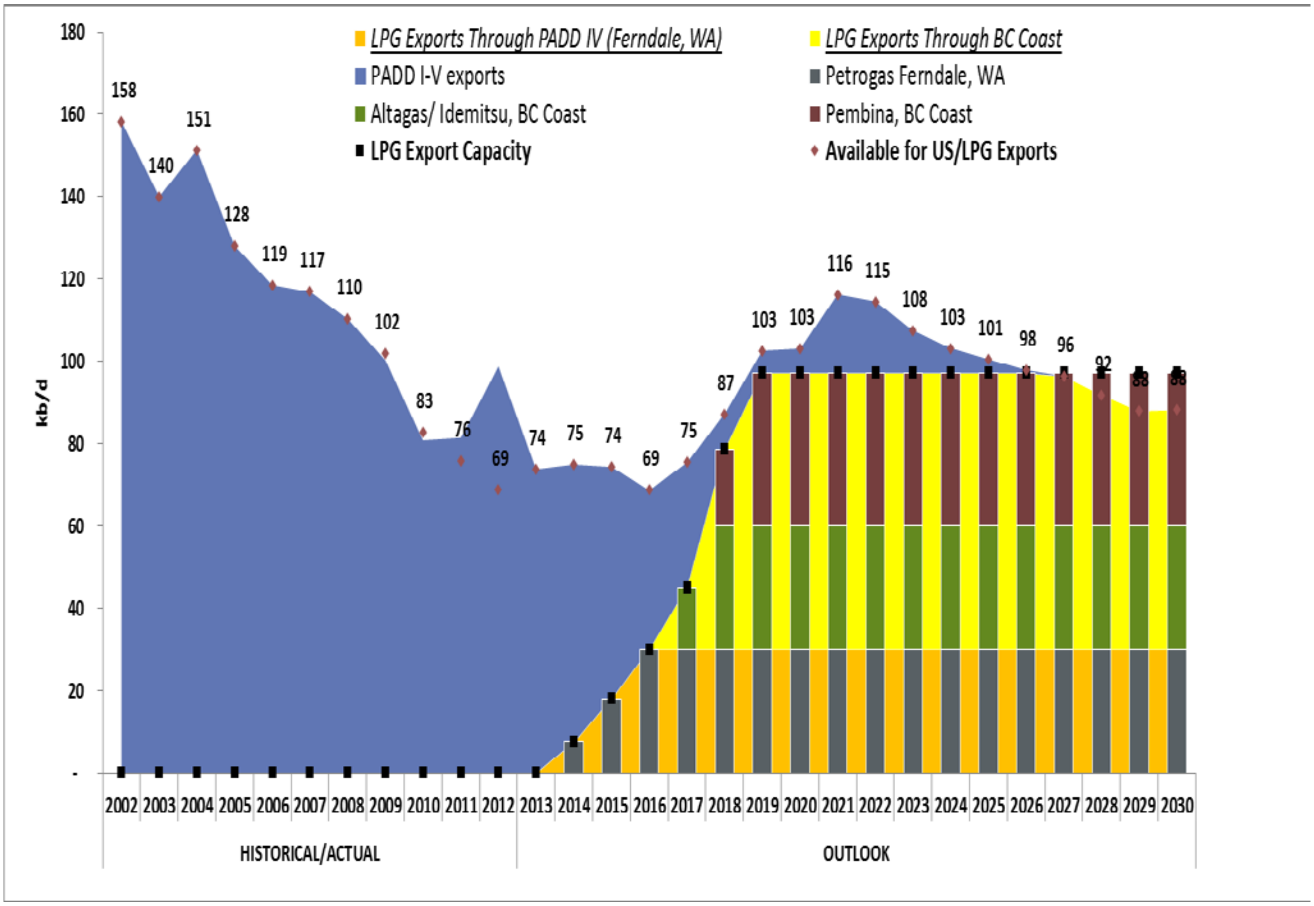


Source: CERI

[55] Except for 2007
[56] Except for 2003 and 2009
[57] http://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/snpsht/2015/08-05xprtsnrth-eng.html

Figure 3.12 shows Canadian propane exports between 2002 and 2030. Canadian propane exports to PADD declined steadily from a peak of close to 151 kb/d in 2004 to a low of about 76 kb/d in 2011, after which point export volumes started to increase, reaching around 98 kb/d in 2012. After 2017, LPG capacity increases steadily, remaining stable and constant through 2030.

Figure 3.12: Canadian Propane Exports by PADD (kb/d) (2002-2030)

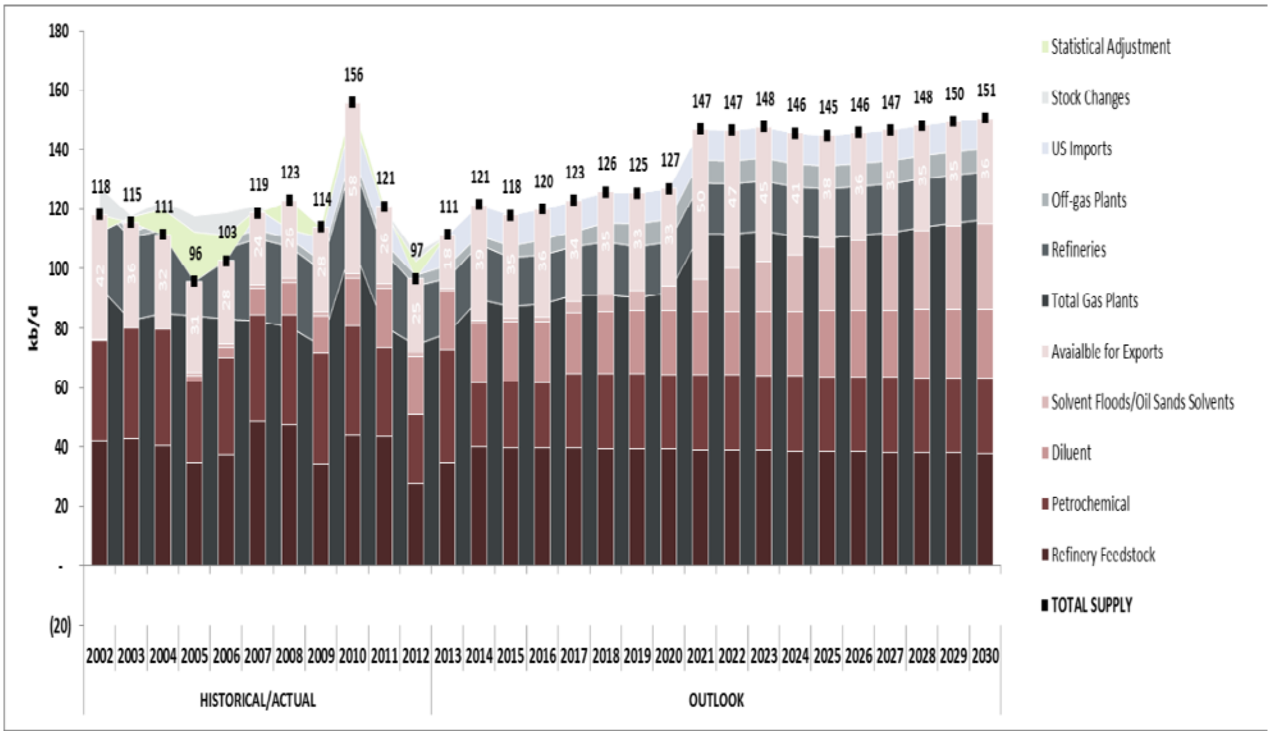


Source: CERI

Butanes Supply and Demand

Figure 3.13 illustrates the supply balance for butanes in Canada. Total supply is the sum of butanes production (from gas plants, refineries, and off-gas plants), US imports, stock changes, and adjustments. Supply volumes have fluctuated between the 123 kb/d (2008) and 96 kb/d (2005 and 2012) range. They were highest in 2010 at 156 kb/d, and are forecasted to increase steadily through 2030. The sharp future increase occurs when butane supply increases from 127 kb/d in 2020 to 147 kb/d in 2021.

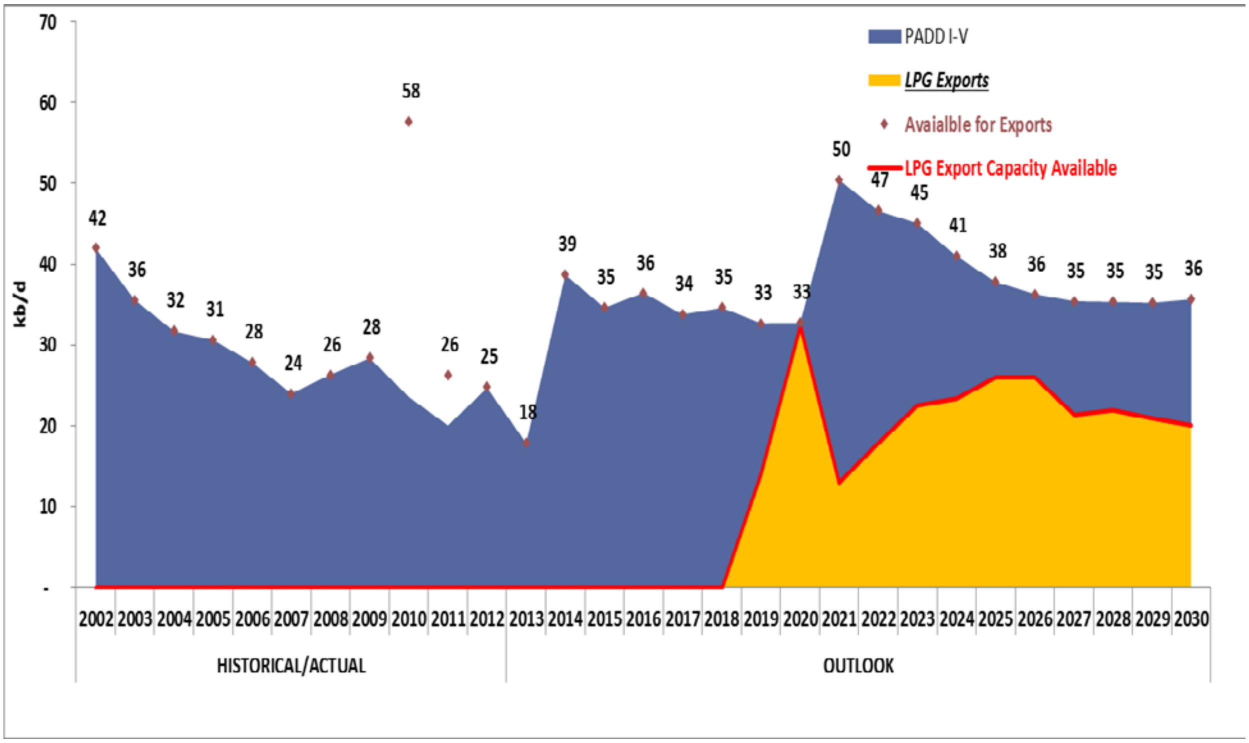
Figure 3.13: Butane Supply (kb/d) (2002-2030)



Source: CERI

Figure 3.14 illustrates Canadian butane exports by PADD. Canadian butane exports declined through 2013, after which point export volumes start to increase through 2019. In 2020, exports to PADD are replaced by LPG exports of 33 kb/d. The total butane capacity available for exports is forecasted to peak to 50 kb/d in 2021 and decline steadily to 35 kb/d from 2027 to 2030.

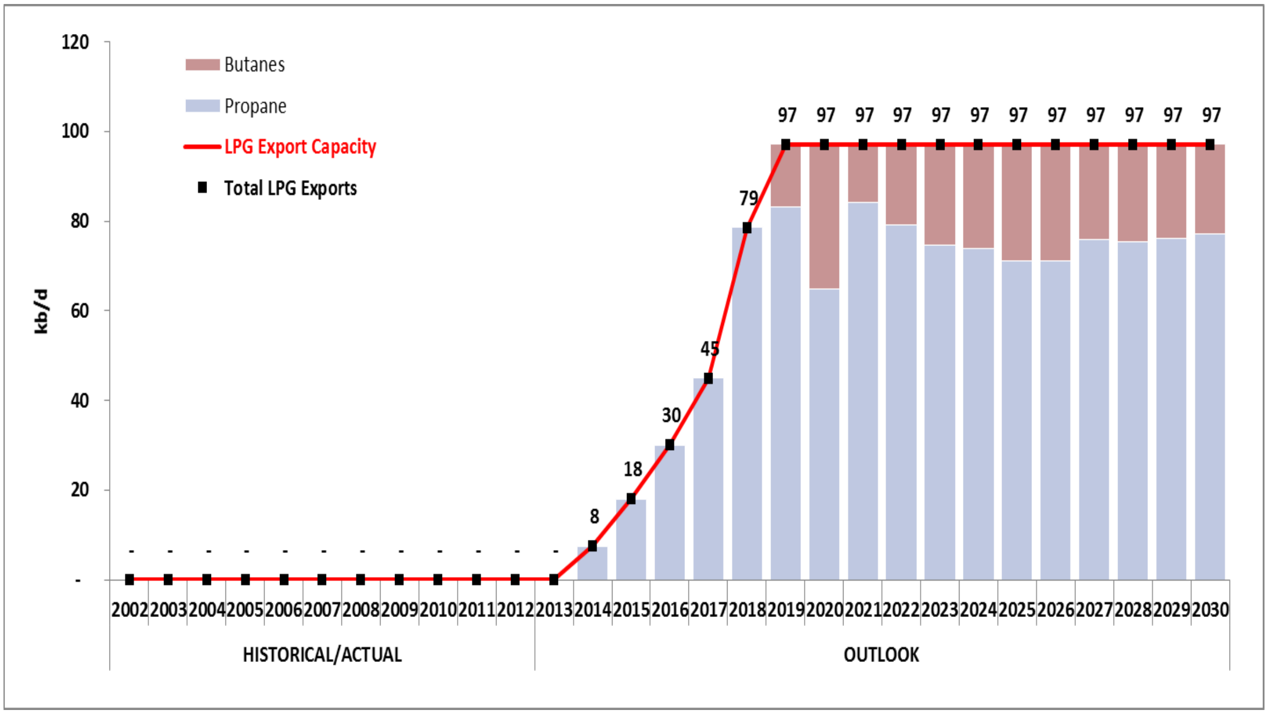
Figure 3.14: Canadian Butane Exports for PADD 1-V (kb/d) (2002-2030)



Source: CERI

Figure 3.15 illustrates Canadian butanes and propane export capacity. Total LPG export capacity is forecasted to rise from 8 kb/d in 2014 to 97 kb/d in 2019, and remain stable to 2030. Propane exports increase steadily through 2021 (except for the decline in 2020 where they are replaced by butane's share), but decline after 2021 to 2030. Butane constitutes about one fifth of the total exports.

Figure 3.15: Canadian Butanes and Propane Export Capacity (2002-2030)



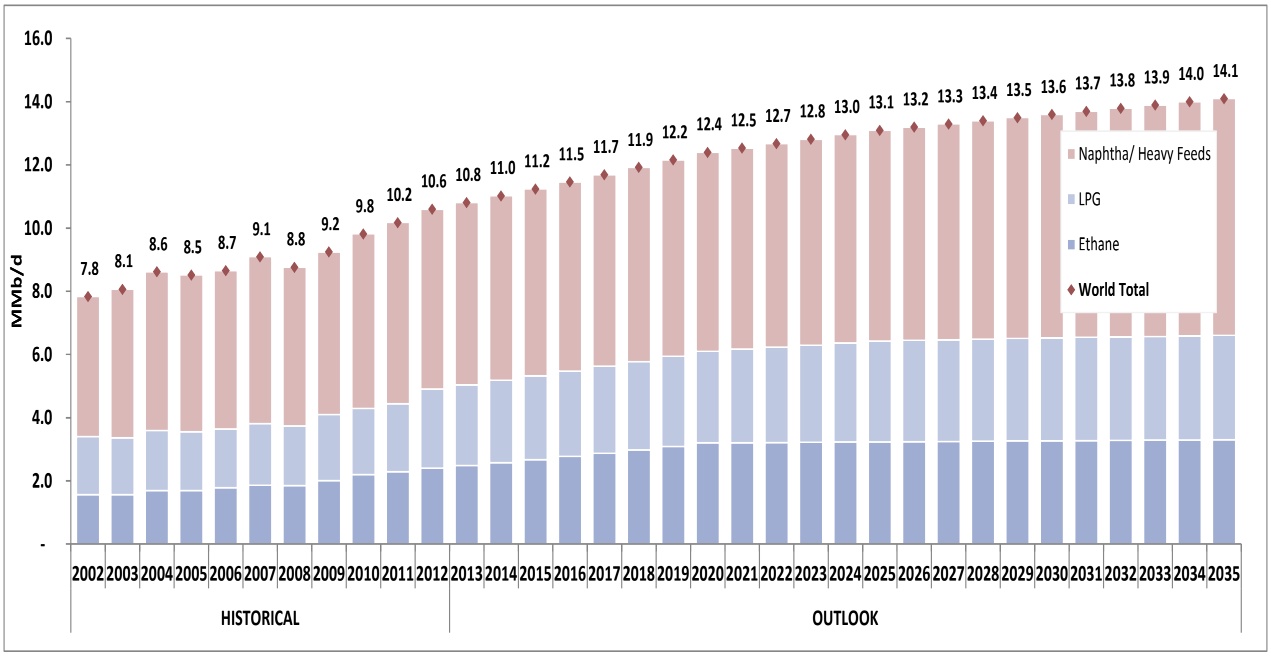
Source: CERI

Global Demand Outlook

The IEA expects demand for NGLs and naphtha as a petrochemical feedstock to continue to increase, albeit at a lower growth rate of 1.2 percent between 2012 and 2035 (Figure 3.16) or by 33 percent reaching a level of 14.1 MMb/d in 2035.

The majority of the 3.5 MMb/d net increase in demand is expected to come from naphtha use (51 percent of increase, or 1.8 MMb/d), followed by ethane, and LPG. This also means that by 2035, naphtha will continue to be the dominant feedstock used for petrochemical production (at 53 percent of 2035's total) compared to ethane (24 percent) and LPG (23 percent).

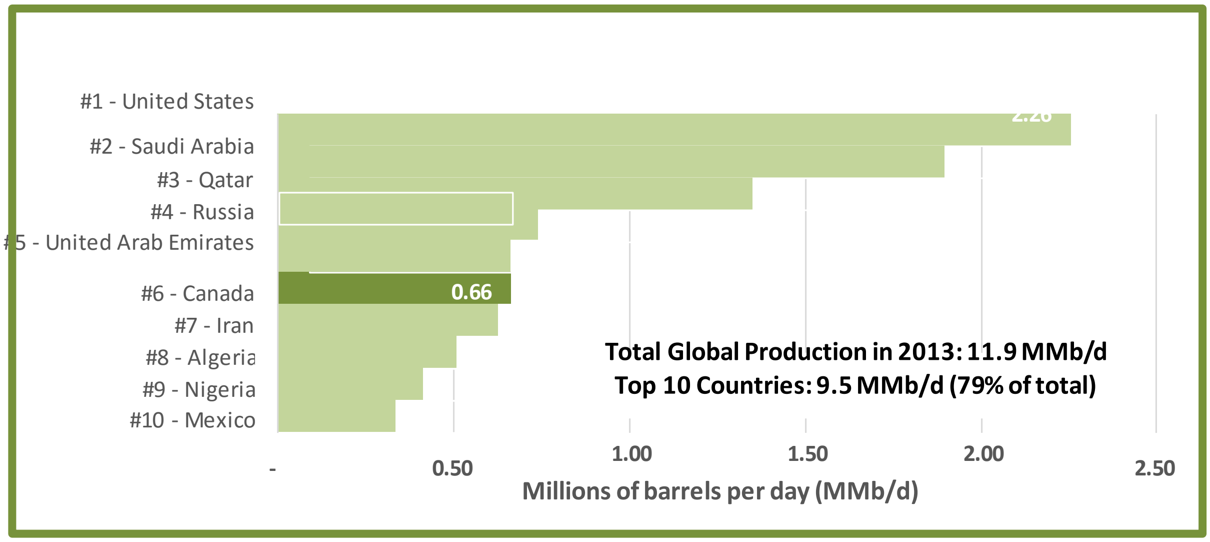
Figure 3.16: Global NGL and Naphtha Petrochemical Feedstock Demand Outlook (MMb/d) (2002 - 2035)



Source: Data from IEA. Figure by CERI

While naphtha will dominate the feedstocks in petrochemicals, the pricing difference between oil based feed stocks and those based on natural gas (i.e., NGLs) will be an important consideration. On a stand-alone basis NGLs will be the more competitive option. Therefore, in the longer term, a greater understanding of where these supplies are concentrated and whether those high petrochemical industries are necessary. Figure 3.17 indicates where the largest NGL supplies originate.

Figure 3.17: Gas Plant NGLs Production by Country in 2013 (Top 10 Countries) (MMb/d)



Chapter 4: International Petrochemical Clusters Case Studies

This section depicts three case studies related to the expansion of other petrochemical clusters from around the world. The countries included are Saudi Arabia, Japan and Korea, and the US Gulf Coast. By drawing on regions with certain differentiating characteristics, Canadian petrochemical clusters may be able to gain some useful insights.

Case Study #1: Saudi Arabia

About two thirds of NGLs are produced by countries outside the Organization of Petroleum Exporting Countries (non-OPEC), where approximately 80 percent of production volumes came from refineries. The remaining volumes of NGLs and naphtha are produced by OPEC countries, with the largest portion (around 84 percent in 2011) coming from gas plants by a handful of OPEC's members including Saudi Arabia, Qatar, the United Arab Emirates (UAE), Iran, Algeria, and Nigeria. Saudi Arabia remains the largest NGL producer among OPEC's members, indicating a large portion of these gas plant NGLs are coming from associated or solution gas tied to crude oil production.[58]

Saudi Arabia is the Middle East region's largest petrochemical producer with an annual 86.4 million tons of capacity. Saudi Arabia produced on average 11.6 million bbl/d of total petroleum liquids in 2013, of which 9.6 million bbl/d was crude oil production and 2 million bbl/d was non-crude liquids production.[59] With the world's largest proven oil reserves and a strategic location, Saudi Arabia is becoming a strategic hub for the expanding petrochemical industry. The country's geographical proximity to the high growth market, expanding production capacity and absolute feedstock cost advantage are significant benefits to the sector.[60] Saudi Arabia has large surplus volumes of LPG available for exports and a dominant position in world LPG trade, allowing them to be the waterborne LPG price setter.

Saudi Arabia is the world's 11th largest petrochemicals supplier, accounting for 7-8 percent of total supply. According to the Royal Commission for Jubail & Yanbu, Saudi Arabia produces over 50 unique petrochemical products. Ethane is the preferred petrochemical feedstock among OPEC members, although Saudi Arabia's petrochemical facilities use small volumes of LPG and naphtha as well. Over the last few years, ethane production and demand has grown rapidly in Iran, Kuwait, and to a lesser extent Qatar and the UAE, yet Saudi Arabia remains the largest user of ethane among OPEC members[61]. There are plans to diversify its petrochemical portfolio from the current ethylene and methanol into more complex, distinctive products such as specialty chemicals and

[58] CERI study "Natural Gas Liquids (NGLs) in North America: An Update; Part IV – Global Markets and Opportunities; May 2014"
[59] US EIA Country Analysis brief September 2014
[60] Saudi Petrochemical Sector All Jazira Capital Research Department Sector reports July 2011
[61] CERI study "Natural Gas Liquids (NGLs) in North America: An Update; Part IV – Global Markets and Opportunities; May 2014"

engineering thermoplastics. For ethylene, Saudi is the world's largest producer accounting for 11 percent of global ethylene production.

The Saudi Arabian Oil Company (ARAMCO) and the Saudi Basic Industries Corporation (SABIC) are the major organizations in the sector. Saudi Arabia has eight domestic refineries, with a combined crude throughput capacity of about 2.5 million bbl/d[62] of which ARAMCO's share is 1.8 million bbl/d approx.[63] The success of the petrochemicals and chemicals industries in Saudi Arabia has been made possible by government support policies. The Saudi Basic Industries Corporation is a public company based in Riyadh, Saudi Arabia and is considered ranked among the world's largest petrochemicals manufacturers. The Saudi Arabian government owns 70 percent of the company, with the remaining 30 percent held by private investors in Saudi Arabia and other countries of the Gulf Cooperation Council.

Saudi Petrochemical Company (SADAF) was established as a joint venture between SABIC and Shell in 1980. SADAF's complex in Jubail was SABIC's first. Further expansions took place in 2000 and 2005 when SADAF commenced production in two styrene plants (offering a combined 1,160,000 ton per annum). Saudi Yanbu Petrochemical Company (YANPET) was founded in 1980 by SABIC and ExxonMobil Corporation to develop a petrochemical complex in Yanbu (opened in 1985) with an initial capacity of 500,000 tpa of ethylene, 200,000 tpa of LLDPE, 220,000 tpa of ethylene glycol and 96,000 tpa of HDPE. Yanbu United Petrochemical Company (Yansab) was established in 2004 to develop the Yanbu Petrochemicals Complex by SABIC holding 55 percent shares, Saudi investors holding another 10 percent and 35 percent garnered from other various private investors.

The advantage for the petrochemical industry in Saudi Arabia include government incentives, supply availability and access to markets.

Case Study #2: Asia Region - Japan and South Korea

JAPAN

After the US and China, Japan is the third largest petroleum consumer and net importer in the world.[64] Due to limited oil reserves, Japan maintains government-controlled oil stocks to ensure against a supply interruption. Of the 420 million barrels of total strategic crude oil stocks, 73 percent are government stocks and 27 percent are commercial stocks.[65]

In 2014, Japan consumed 4.3 million barrels per day (bbl/d). Most of its oil is consumed in the transportation and industrial sectors[66]. Additionally, Japan is also highly dependent on naphtha

[62] Oil and Gas Journal, "Worldwide Refining Capacity Details" (January1, 2014)
[63] Saudi Aramco, "Annual Review 2013" page 33
[64] EIA Japan Jan 30, 2015 Full report
[65] International Energy Agency October 2015
[66] Petroleum Association of Japan, Petroleum Industry in Japan 2014

and low-sulfur fuel oil imports. The majority of Japan's domestic oil supply is obtained in the form of refinery grain, resulting from the country's large petroleum refining sector. The country has 148 producing oil wells in over a dozen fields.[67] On the supply side, production of petroleum and other liquids was an estimated 136,000 bbl/d, of which only 18,000bbl/d was from crude oil and natural gas liquids.

Production of non-OPEC refinery LPG and naphtha has increased rapidly over the last decade. This is primarily led by increases in production from the Asia-Pacific region given increased crude oil and overall energy demand in the region. Production and demand has been relatively flat in the Asia-Oceania area (Japan, Korea, Australia, and New Zealand). Condensate refining is the last significant source of NGLs and naphtha demand among non-OPEC countries. Demand for condensate as a refinery feedstock is high in the Asia-Pacific region (primarily in Japan). Import requirements are the highest among the Asia-Pacific region with large levels of imports required in countries such as Japan, Korea, India, and China.[68]

Japan has the third largest refining capacity in the Asia-Pacific region, with over 4 million bb/d of crude oil refining capacity at 23 facilities. The largest oil refinery company, JX Nippon operates five refineries with about 1.1 million bbl/d of capacity. Idemitsu Kosan, Cosmo Oil, and Tonen General Sekiyu are other key operators. The refining sector has encountered excess capacity in recent years, because domestic petroleum product consumption has declined, due to the contraction of industrial output and the mandatory blending of ethanol into transportation fuels. Japanese refineries are faced with competition from new refineries in emerging Asian markets, as well as lower domestic demand. Some strengths of the country include a high level of specialization and value which enable producers to stay ahead in competition with low-cost Asian and Middle Eastern producers, while some weaknesses include high debt, lack of domestically produced naphtha feedstock, high dependence on imports, and high cost of transport and machinery.[69]

The main advantage for the petrochemical industry in Japan is access to markets.

SOUTH KOREA

South Korea is one of the top energy importers in the world and relies on fuels imports for about 97 percent of its primary energy demand. Korea lacks domestic energy reserves and has no international oil or natural gas pipelines. Therefore it relies exclusively on tanker shipments of LNG and crude oil.[70] South Korea relies significantly on crude oil imports to meet its demand. A majority of South Korea's total oil production of 60,000 bbl/d is based on refinery processing gains and a small portion of biofuel production. The country is one of Asia's largest petroleum

[67] Oil and Gas Journal, Worldwide Production, December 1, 2014
[68] CERI study "Natural Gas Liquids (NGLs) in North America: An Update; Part IV – Global Markets and Opportunities; May 2014"
[69] Business Monitor international – Japan Petrochemicals report 2015
[70] EIA

product exporters with about 1.2 million bbl/d of refined products exported in 2013 mostly in the form of gasoil and jet fuel.

South Korea is the world's 5th largest chemical production country, and a major producer of petrochemicals, with 7.3 million tons per year of ethylene capacity. It is home to the single largest aromatics (includes petrochemicals such as benzene and its derivatives) production site in the world, owned by GS Caltex. Naphtha, which is used for South Korea Petrochemical and industrial sectors, account for about 44 percent of total oil product demand and is the primary driver of domestic demand growth. Outside of the Petrochemical sector, oil demand growth is limited in the long term due to factors like declining population growth, greater energy efficiency measures, and competition from other fuels such as natural gas, nuclear, renewable sources.

South Korea has the sixth-largest refining capacity in the world. Major oil refineries include South Korea Innovation, GS Caltex Corp, S-Oil Corp, Hyundai Oil Refinery. Korea is one of the prominent petrochemical producers in the world, with overall annual ethylene capacity of 5,700 thousand tons and various accompanying downstream plants[71]. Within the Asia-Pacific region, countries such as China and Indonesia will continue to suffer from a deficit of ethylene and propylene's main derivatives, polyethylene and polypropylene, while countries such as South Korea and Singapore will continue to produce levels above and beyond their domestic needs.[72]

Petrochemicals production facilities are located at three main centres in South Korea namely, Ulsan, Yeochun and Daesan, and a smaller complex in Onsan.[73] Ulsan accounts for around 35 percent of Korea's total production. Two hundred and three companies in Ulsan recorded KRW 135 trillion in production, the biggest scale among the city's three major industries. It also accounts for USD 45.3 billion in export in 2013, 40 percent of the nation's chemical industry. Ulsan is home to Asia's largest chemical industrial complex as well as some of the leading chemical companies in the world such as South Korea Energy, S-oil, Solvay, Eastman, Rhodia, BP, Mobil and DuPont.[74] The main cracker operators are Hanwha Chemical, Honam Petrochemical, LG Petrochemicals, Samsung, and SK Corporation. Others include Lotte Chemical, LG Chem, GS Caltex, KPIC, and Samsung Total Petrochemicals.[75]

	Ulsan	**Yeochun**	**Daesan**
Year built	1970s	1979	1980-90
Annual production Capacity	3 units naphtha cracker Production-1130 thousand tons of ethylene annually	5 units naphtha cracker Production-2890 thousand tons of ethylene annually	3 units naphtha cracker Production-1680 thousand tons of ethylene annually

[71] http://www.apic-online.org/countrydata_korea.htm
[72] CERI study "Natural Gas Liquids (NGLs) in North America: An Update; Part IV – Global Markets and Opportunities; May 2014"
[73] http://www.kpia.or.kr/eng/industry/pcind_01.html
[74] http://www.investkorea.org/ikwork/reg/eng/co/index.jsp?l_unit=90202&m_unit=90309&code=1410302
[75] Business Monitor international – South Korea Petrochemicals report 2015

Demand for naphtha, which is used as the country's sole petrochemical feedstock, is increasing with the development of naphtha-based aromatics capacity. Due to its demand from the petrochemical sector, naphtha's share in South Korean total refined oil production rose from about 17.9 percent in 2009 to 22 percent in 2013.[76]

Some strengths of the country include large refining and olefins capacity and their ideal position to take advantage of growing Chinese demand. Some weaknesses include, hydrocarbon feedstock needs to be imported, highly reliant on overseas demand and a feedstock cost disadvantage compared with other nations. The petrochemical industry in South Korea is diversifying feedstock sources and aiming to reduce naphtha feedstock usage to liquefied petroleum gas, which has been prompted by an increase in LPG supplies from US and the advantage of cheaper feedstock to the US petrochemical companies due to a boom in shale gas.

Case Study #3: United States Gulf Coast (USGC)

The petrochemicals industries in Canada and the US are structurally quite similar. In the US, the major petrochemical producing region is along the Gulf Coast (47 percent of total US refining) in Texas and Louisiana. Texas leads the US in total energy production, primarily crude oil and natural gas production.[77] The industrial sector accounts for the largest share of energy use in Texas. The state has many energy-intensive industries, including petroleum refining and chemical manufacturing. It has almost one-third of the US total crude oil reserves.

The largest refining center in the United States is located along the Texas Gulf Coast. With 27 petroleum refineries that can process more than 5.1 million barrels of crude oil per day, Texas leads the nation in crude oil refining capacity. More than one-fourth of nation's total refining capacity is located in Texas. The majority of the state's refineries are clustered near major ports along the Gulf Coast, including the Houston area, Port Arthur, and Corpus Christi. Refineries on the Texas Gulf Coast, including the nation's largest refinery in Port Arthur, form the largest refining center in the United States. These coastal refineries have access to local Texas production, foreign imports, and crude oil produced offshore in the Gulf of Mexico. North America is emerging as a potentially significant net exporting region, which could pose a challenge to OPEC dominated LPG prices and supplies on the global market.

Many of the Texas refineries are sophisticated facilities that use additional refining processes beyond simple distillation to yield a larger quantity of lighter, higher-value products, such as motor gasoline. Texas leads the nation in total petroleum consumption, and it is first among the states in the consumption of distillate fuel oil and liquefied petroleum gases (LPG). Almost all of the LPG is consumed by the industrial sector where it is used as a chemical feedstock in petrochemical plants. The production of chemicals in Texas makes up the largest manufacturing

[76] Business Monitor international – South Korea Petrochemicals report 2015
[77] http://www.eia.gov/state/analysis.cfm?sid=TX

industry in the state.[78] The Houston vicinity, including Freeport, Bay City, and Texas City, has the heaviest concentration of plants. Second in size is the chemical industry of Beaumont-Port Arthur-Orange. Other major centers near the coast are Brownsville, Corpus Christi, Victoria, and Seadrift.

Louisiana is the other number one producer of crude oil in the US, and the number two producer of natural gas. Roughly 88 percent of the country's offshore oil rigs are located off Louisiana's coast.[79] The Greater New Orleans region is the state's energy hub, home to six refineries and petrochemical plants. Louisiana is a major producer, processor and transporter of domestic energy with 88 percent of the nation's oil rigs off the coast, and has 50 million tons of crude oil refined and distributed through the United States. Louisiana can refine more than 2.9 million barrels of gasoline per day, which is the second largest capacity in the US.[80] This makes Louisiana the second largest petroleum product producing state, after Texas. Louisiana's facilities feature many enhanced refining processes that far exceed simple distillation. This allows them to yield a larger quantity of lighter, higher value products, such as gasoline.

There are more than 300 major chemical plants located in Louisiana which export nearly $4.5 billion in chemical products a year. Federal, state and local incentives available to the energy, petrochemical and plastics industry in the Greater New Orleans region comprise one of the most aggressive, and potentially lucrative financial packages in the nation. The energy, petrochemicals and plastics industry in the Greater New Orleans region benefits from a complex transportation infrastructure such as ports, highways, railroads and pipelines, providing easy access to the rest of the world.

Traditionally, the US has been a net importer of NGLs. Nevertheless, with the proliferation of shale-gas production and the associated NGL production, imports have switched to exports. Historically, the US has had virtually no imports or exports of ethane, only transfers within the US. Again, this is changing as dedicated ethane pipelines are built from producing areas in the US to petrochemical facilities in Canada. US petrochemical facilities are also able to absorb much of the increased supply of ethane as they switch away from other NGLs and heavier petroleum-based naphtha feedstock in ethylene crackers to lighter feedstock. Recent record low NGL prices have motivated petrochemical companies to maximize the amount of ethane and propane in their feedstock.[81] Going forward, the main constraint on ethane availability in the US will remain on the demand side rather than on the supply side. When and where demand will expand at which rate will depend on infrastructure availability, re-tooling and expansion of currently existing ethylene crackers, and the possible building of new crackers, as well as possible overseas exports and increased exports to Canada (subject to capacity expansion and changing market dynamics).

[78] http://www.tshaonline.org/handbook/online/articles/dmc01), accessed June 19, 2015. Published by the Texas State Historical Association

[79] http://gnoinc.org/industry-sectors/energypetrochemicalsplastics/

[80] http://setxind.com/downstream/louisiana-oil-gas-industry-growth-refineries-petrochemical-plants/

[81] Energy Information Administration, April 2013, Annual Energy Outlook 2013, with Projections to 2040, http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf

The increased supply of propane has caused producers to look for alternative domestic markets for their products (as well as increasingly, exports), including the marketing of propane as an alternative vehicle fuel and for agricultural use. Propane also has the advantage of flexibility in mode of transportation. Propane can be moved by pipeline, ship, train, or truck. Consequently, it is often used as a fuel for heating in remote areas, and its use is highly seasonal, peaking in the winter months. While production of propane has been increasing over the past five years, consumer demand has been falling. Demand for propane is down in the petrochemical markets as it has been less competitive than ethane. While in the heating market, a shift to natural gas appliances is affecting demand levels throughout the country. The result has been an increase in exports of propane; such that the US is now a net exporter of propane.

Demand for normal butane has fallen in recent years in the petrochemical sector, as it is not as competitive as ethane for production of ethylene. However, butane is also used for other petrochemicals, including butadiene, used for making synthetic rubber for tires, belts and hoses, and demand for these products continues to rise. The market for butane is typically balanced by increasing export demand from Mexico, South America and Europe.[82]

The future evolution of NGL supply and demand balances will rest on the ability of the industry to build enough infrastructure in a timely fashion to deliver increasing supply from existing and emerging areas to both expanding domestic industries (such as petrochemicals) and also increasingly to Canada (most NGLs) and the global LPG market.[83]

The US advantage is lower price feedstocks plus an integrated infrastructure allowing ease of access to local markets and exports. Supply availability is also an advantage for the petrochemical industry.

Comparative Analysis

The above studied regions may be different in terms of market drivers (feedstock availability, domestic demand, open markets), demand and consumption patterns (population, economic status and growth), and outlook for investment (existing infrastructure, investment environment, economic/political stability). Players in the petrochemical market need to adapt to shifting drivers such as proximity to demand, access to feedstock, access to talent and technology and supportive government actions.

Table 4.1 provides a brief comparison between these different case study regions.

[82] Targa Resources, Third Quarter 2013 Reported Results & 2013 Investor & Analyst Conference, November 5, 2013 http://files.shareholder.com/downloads/NGLS/2923014341x0x703058/2f47d5ad-5ae6-40a5-8183-d76bac17551c/WEB_131101_2013_Targa_Investor_Presentation.pdf

[83] http://ceri.ca/images/stories/2014-05-06_CERI_Study_139_Part_III.pdf

Table 4.1: Comparison between the Different Regions

Factors	Saudi Arabia	US Gulf Coast	North East Asia: Japan and Korea	Canada
2014 Capacity (Ethylene Crackers kt/year)[84]	13,155	28,121	Japan 6,935 Korea 5,630	5,531
Primary Feedstock	NGLs (ethane, LPG)	NGLs	Naphtha	NGLs
New construction 2015 (added capacity tpy)	5,818,000	1.2 billion lb/yr expansion +9,867,133	Japan 300,000 Korea 1,420,000	None
Feedstock pricing	Cheap feedstock ($0.75-$2.50) Government determined Attractively priced gas and liquid feedstock in a highly competitive petrochemical infrastructure offers attractive project economics; long-term feedstock supply security is unparalleled Eg: Ethylene production cash cost of an ethane-feed plant = $150-200/mt	($2.50-$3.00) Determined by market prices Eg: Ethylene production cash cost of an ethane-feed plant = $400-500/mt[85]	$417/tonne Japan-dependent on internal refineries and imports at market prices Korea- dependent on naphtha as sole petrochemical feedstock and imports at market prices.	Long-term agreements and market prices – with a discount of approximately $0.50 compared to the US gulf coast. Similar production cost in comparison with the US gulf coast
Major players	Government sponsored companies: Saudi Basic Industries Corporation (SABIC), Saudi	Private companies: Lyondellbasell, CP chemical, Dow Chemical,	Private companies: Japan: Sumitomo Chemical Korea: -SK Energy, KPIC, S-oil, Kumho	Private companies: Nova chemicals corporation,

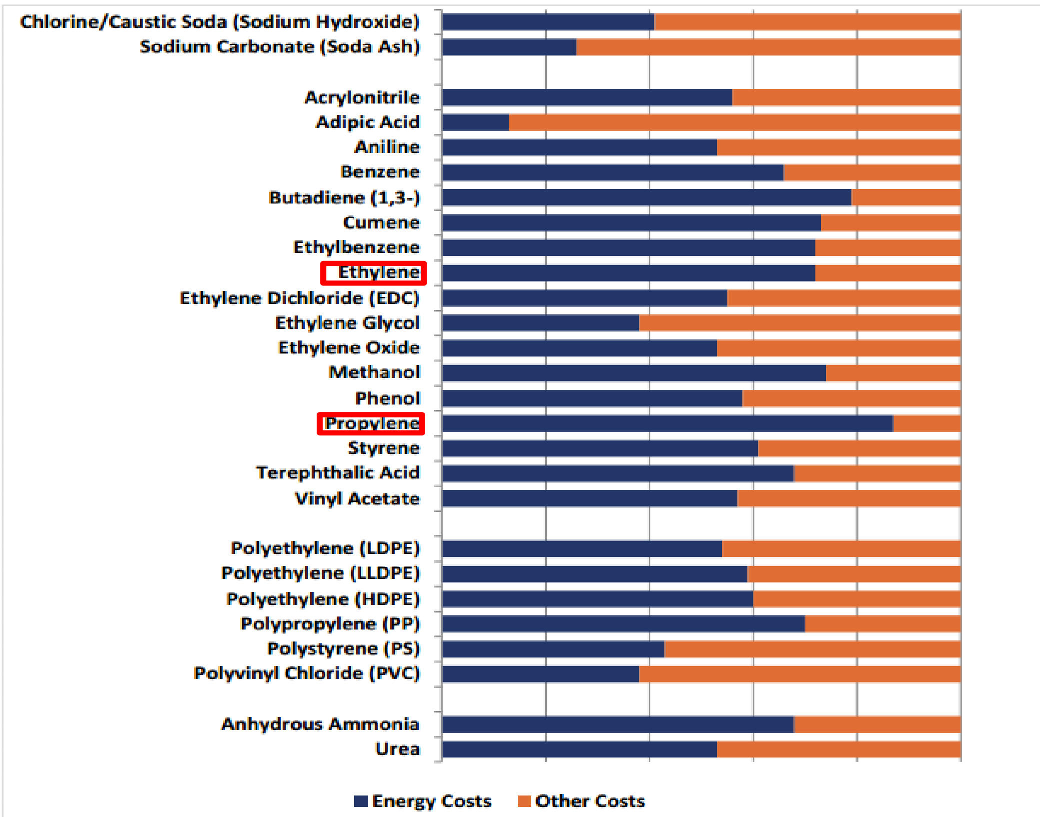
[84] Oil &Gas Journal's surveys
[85] Al Jazira Capital-Saudi Petrochemical sector- http://www.aljaziracapital.com.sa/report_file/ess/SEC-8.pdf

Factors	Saudi Arabia	US Gulf Coast	North East Asia: Japan and Korea	Canada
	Petrochemical Company, Saudi Kayan Petrochemical Company, Yanbu National Petrochemical Company	ExxonMobil Chemical, DuPont Chevron Phillips	Petrochemical, ISU Chemical	Akzo Nobel chemicals Ltd., and Dow Chemical Canada
Feedstock supply/ availability	Local production: High crude and NG reserves Ethane feedstock	Local production: High crude and NG reserves	Heavily dependent on naphtha as feedstock; Imported supplies	Abundance of natural gas in US and Canada will help keep costs low
Estimated costs of building new facilities (examples) [86],[87]	Yanbu Project: Polypropylene Capacity tpy:420,000 New: $700 million Saudi Chemical Co.-Jubail Industrial city Project: Propylene oxide, propylene glycol, linear low density polyethylene, low-density polyethylene New:$20 billion	Ingleside Ethylene LLC-Ingleside, Texas Project: Ethylene 1.2 billion lb/year New: $1 billion Sasol-Lake Charles, Louisiana Project: Ethylene 1,500,000 tpy New $5-7 billion	South Korea: Hyosung Corporation Project: Propylene plant, Ulsan Capacity:300,000 tpa New: $266 million	n/a

[86] Oil &Gas Journal's surveys Nov.3 , 2014
[87] Business Monitor international – South Korea Petrochemicals report 2015

The viability and competitiveness of the petrochemical industry's expansion in Canada (and North America) will be determined by the global demand for petrochemicals, continued local feedstock availability and price advantage, and the relative production costs of competitors worldwide.

Figure 4.1: Energy (feedstock, fuel, and power) Costs Share (%) of Total Production Costs by Product



Source: ACC[88]

Given that production of olefins is highly energy-intensive, that is, the feedstock (NGLs and naphtha) as well as fuel and electricity costs account for the largest share of production costs (as seen on Figure 4.1); regional feedstock price disparities translate into production cost advantages or disadvantages.

Meanwhile, global prices for olefins and their derivatives are dictated by a combination of global economic conditions and consumer demand, energy and feedstock prices, but more importantly, the cost structure of the marginal producer which is required to satisfy a given level of demand (usually the highest cost producers). This means that the feedstock cost advantage generally stays with the low cost producers and translates into higher margins, but not necessarily lower

[88] American Chemistry Council (ACC), Shale Gas, Competitiveness, and New US Chemical Industry Investment: An Analysis Based on Announced Projects: http://chemistrytoenergy.com/sites/chemistrytoenergy.com/files/shale-gas-full-study.pdf

olefin and derivative prices.[89] Higher margins however, can fuel re-investment and expansion cycles.

In the context of petrochemical industry expansion, the Canadian petrochemical industry is currently one of the most competitive on a global basis, based on feedstock and thus production costs. This is the case as the industry relies predominantly on lower priced lighter feedstock such as ethane and propane, while about half of the world's capacity is configured to run on heavier feeds such as naphtha, for which prices are mainly driven by global crude oil markets

Regional price disparities translate into competitive advantages (or hindrances) for overall NGL end-users, but in particular, petrochemical producers as well as other energy-intensive industries able to produce their own output (such as ethylene or propylene) at a lower cost compared to their global peers.

In regards to feedstock type, naphtha is the single largest feedstock source estimated to account for at least 45 percent of global capacity (65 MMt) followed by ethane at 27 percent (38 MMt), other feedstock[90] at 11 percent (15 MMt), with the remainder of capacity (17 percent or 24 MMt) using propane, gas oil, butane, and other non-specified feedstock.

Given that light feedstock such as NGLs (ethane, propane, butane) tend to cost less than refinery naphtha,[91] regions that have access to available NGL supplies tend to have lower ethylene production costs, achieve better margins, and be more competitive. In that context, Canadian petrochemical producers are some of the most competitive in the world in terms of feedstock cost advantage. Going forward, given expansion plans for the petrochemical industry in Canada and compared to its global peers, the fortunes of petrochemical producers will partially rest on maintaining the feedstock cost advantage based on reasonably priced and readily available local feedstock.

In addition to feedstock, other costs are involved in the production of petrochemicals. For example, the economics of ethane use and production are as follows.[92]

1) Variable cost of production includes the costs of raw materials, feedstocks plus catalysts and chemicals, and utilities at cash cost or purchase cost, with a credit for co-products.
2) Direct fixed costs include salaries for operating staff plus associated on-costs such as holiday cover, social insurance, fringe benefits etc.
3) Maintenance costs including materials and labour.
4) Allocated fixed costs are the site charges which are necessary for production.

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89 This is the same case as refineries in the US Midwest having access to discounted North American crudes, which were turned into higher refiner margins rather than lower gasoline prices, as gasoline is a globally traded commodity priced according to global fundamentals

90 Generally refers to NGL and LPG mixes as well as refinery gases or a mix of various feedstock types

91 IEA's WEO 2013 estimates supply of naphtha in 2012 to be about 6.5 MMb/d (90 percent from refineries) and petrochemical demand to be about 5.7 MMb/d or about 88 percent of supply. This also implies that of the 10.6 MMb/d of petrochemical feedstock used in 2012 about 54 percent was naphtha

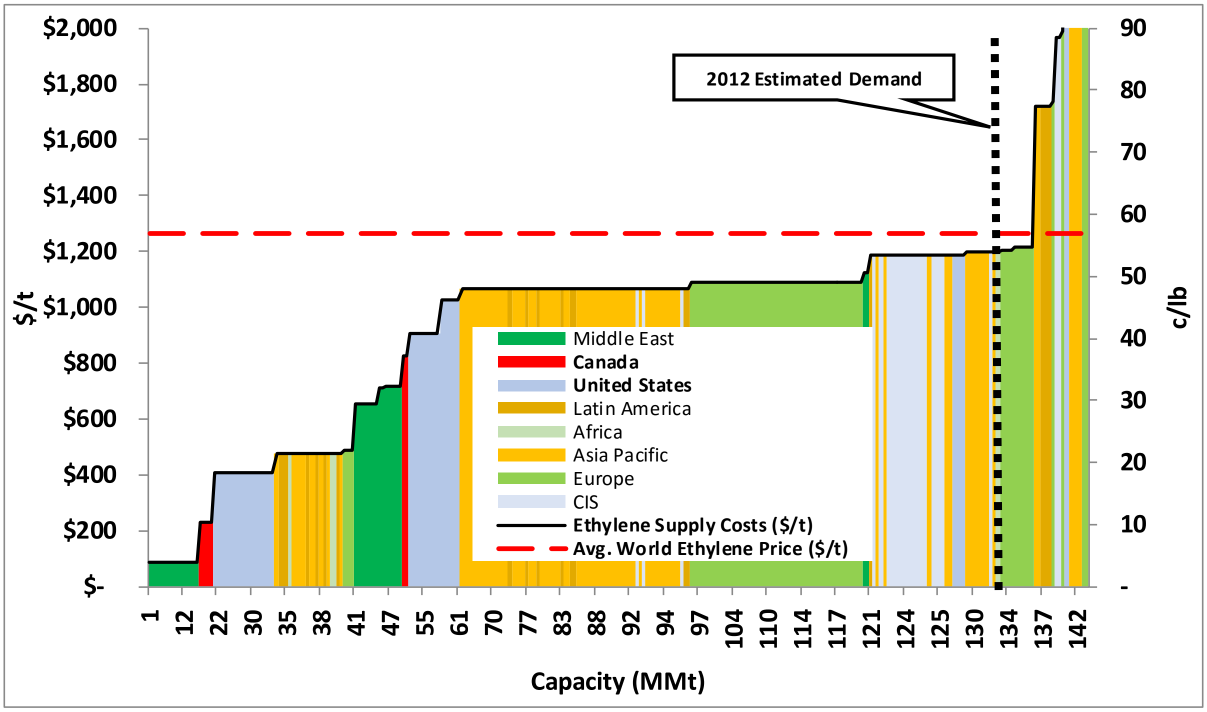
92 Nexant report 2015

5) Freight and handling costs; tariff involved in delivering the polyethylene to a particular target market to calculate the total delivered cost.
6) Capital related charges of depreciation plus a simple return on investment are added to characterize total costs.
7) Other costs: Innovation (short and long term); exchange rate; regulatory burden; tax burden; value chain breadth; and transport infrastructure.

Petrochemical companies globally are responding to disruptions in supply and demand by adapting their business models, which include improving scale, operational efficiencies, and value chain integration to drive down costs. A 2012 study by the consulting firm KPMG indicated that chemical manufacturing in Canada costs less by about 3 percent compared to the US and 7 percent less than Japan. This assessment does not include the cost advantage to Canada with respect to feedstocks, nor the added cost in western Canada to move petrochemicals or their derivatives to tidewater.

Figure 4.2 compares ethylene supply costs for the most recent year a complete set of costs was available (2012). The figure shows the cost competitive nature of Canadian petrochemical manufacturers. The Middle East has the greatest cost advantage but this is due to incentives making their feedstocks artificially low. Canada and the US are the next most competitive regions, followed by Latin America and some parts of the Asia Pacific region. This cost information is from 2012, and recent information regarding investment costs indicates the cost differentials between Canada and the US and globally between ethane and naphtha based processes are narrowing. Naphtha based manufacturers have gained a stronger competitive position in 2015 resulting from the drop in oil price. This chart for 2012 was developed with oil prices in the $90 to $100 per barrel range. Currently oil price is averaging $50 to $60 in 2015. That will shrink the cost advantage for North American ethylene production.

Figure 4.2: 2012 Global Cost Comparisons



Sources: Data from ADOE, Dewitt & Company, EIA, Federal Reserve Bank, GAE, HKEMSD, IEA, IMF, OECD, OGJ, PWC, SGL, UNEP, World Bank, and CERI estimates. All figures by CERI

Chapter 5: Conclusion

The petrochemical sector in Canada is cost competitive with other regions globally. The main reason is the access to cheap feedstock. North American petrochemical production is dominated by NGL feedstocks. Other regions source their feedstock from crude oil and naphtha. The cost advantage in North America is greatest with a wide margin between the price for natural gas and oil.

A report from Wood Mackenzie analyzed the cost of ethylene production at various oil and natural gas prices. With oil at a $100 price per barrel, ethylene production costs from naphtha range between 45 and 50 cents per pound. At $70 per barrel, ethylene production costs drop to slightly more than 30 cents per pound.

Similarly, their report indicates that at a $4 per mmbtu for natural gas, the ethylene production costs is approximately 15 cents per pound. This would increase to the 20-25 cents per pound at $7 per mmbtu for natural gas.

Figure 5.1 shows how the price advantage in North America can change with the price of oil and gas. With the August 2015 Brent crude price moving in the $50 to $60 range, that would suggest a naphtha based price for ethylene in Asia of less than $0.30 per pound. North American ethane based ethylene is cost competitive at $0.10 to $0.20 per pound. However, transportation cost to the growing Asian market would increase this cost.

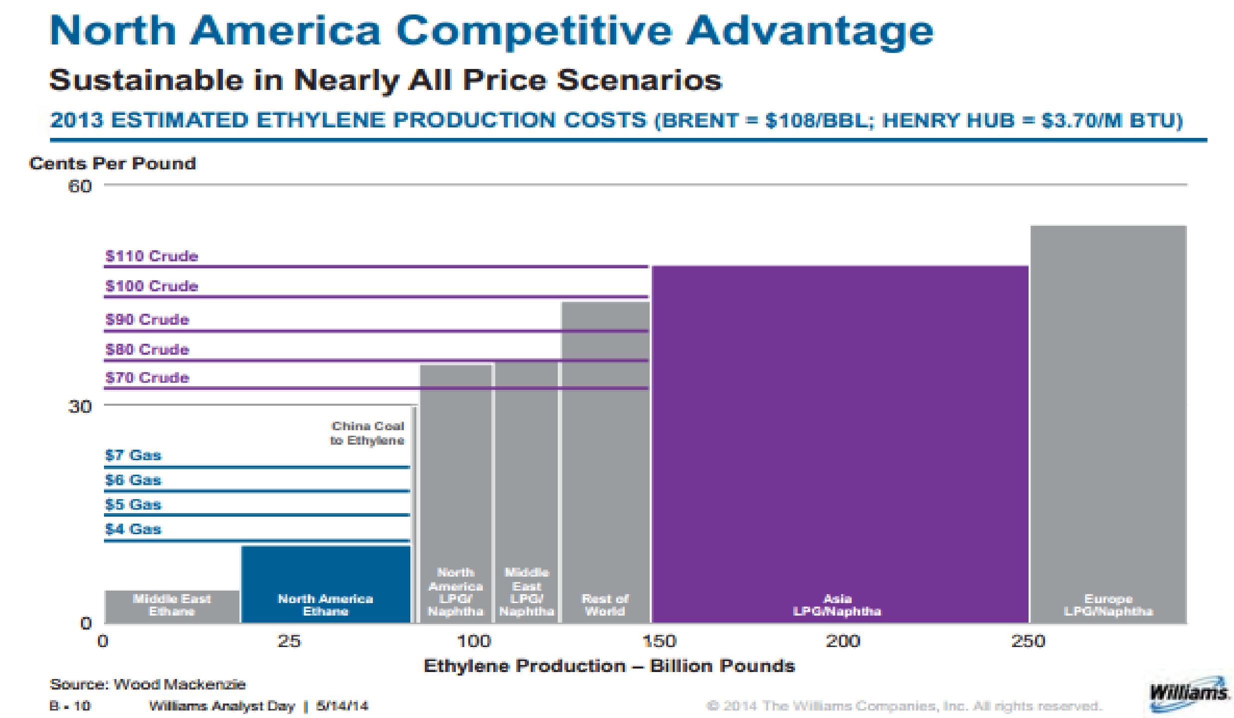
Long term, there is a structural price advantage in North America as a result of feedstock costs.

Feedstock availability is another advantage. In Canada, there is an additional 300,000 to 350,000 bbls/d of ethane availability, sufficient for 2 to 3 additional world scale crackers. Capacity utilization in Canada is high averaging above 90 percent. While there is some excess capacity, it remains to be seen if the utilization rate can be moved up to the 95 to 100 percent range. If not, one observation is that there is no significant excess capacity at this time in Canada.

Market access remains a challenge if expansion is to occur in Canada. The petrochemical sector has been built to serve the domestic and US markets. These markets show little potential for growth either due to a lack of increase in demand or increased capacity in the US to serve that market.

Overseas market access would be needed to facilitate expansion of the sector in Canada. In the east, this access challenge is due to the far distance between producers and the market. In the west, the challenge is to move product from Alberta to the BC coast. Rail is the most likely option. Although pipeline access would be cheaper, the social acceptance of pipelines is difficult to obtain. According to the 2015 Chemical Industry update of the Conference Board of Canada, one weakness of the chemicals industry is the decline in access to rail transportation and insufficient pipeline capacity, which threatens the industry's cost structure.

Figure 5.1 Price Margin Comparison between Crude Oil and Natural Gas



Expansion of the petrochemical industry in Canada is a reasonable option, when compared to the other regions of the world. There are cost advantages primarily in sourcing low cost feedstock. Canada is also fortunate to be in close proximity to import regions. The challenges of the export market and in particular the transportation infrastructure to tidewater remain.

Other risks to the petrochemical industry include price volatility, infrastructure bottlenecks, labour supply shortages, business and environmental regulations affecting and of course customer demand.[93] However, these challenges are experienced by all petrochemical companies to a greater or lesser degree, and should not cause a significant market differentiation between Canada and other petrochemical regions.

[93] Petrochemical Supply Chain and export logisitics:Update 2015